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ILLUSTRATIONS.

PREFACE.

By F. L. Ransome.

In response to numerous requests from persons interested in the development of the mineral resources of Wyoming and desirous that reliable information concerning them should be published, A. C. Spencer, geologist, was detailed in 1914 to make an economic reconnaissance of the region adjacent to South Pass City, Miners Delight, and Atlantic City, in Fremont County, and of parts of the North Laramie Mountains, in Converse and Albany counties. The two areas examined by Mr. Spencer lie about 125 miles apart, the Atlantic gold district being in west-central Wyoming about 20 miles south of Lander, and the North Laramie Mountains in the southeastern part of the State, south of Douglas and Casper.

The Atlantic district has produced considerable gold, estimated by Mr. Spencer at about $1,500,000, although other estimates vary up to nearly $6,000,000. No large mine has been developed in the district, however, and of late years mining activity has declined. In the North Laramie Mountains mining development remains in the prospecting stage. In both regions the lode deposits occur in schists of pre-Cambrian age, partly with quartz in distinct fissures and partly as tabular or lenticular bodies of rock through which the sulphides are distributed. These bodies are aligned in more or less definite belts in the schist. The chief metal in the prospects of the North Laramie Mountains is copper, although other metals are also present in most of the lodes.

The area shown on the geologic map of the North Laramie Mountains (Pl. IV), which is based largely on the work of N. H. Darton, overlaps to the south an area previously mapped geologically on the same scale by Darton and Siebenthal [1] and to the north the area covered by Darton's geologic map of the central Great Plains.[2] Adjacent to it on the west is an area that will be covered by a map to accompany a report now in preparation by C. J. Hares. The work on which

[1] Darton, N. H., and Siebenthal, C. E., Geology and mineral resources of the Laramie Basin, Wyo.: U. S. Geol. Survey Bull. 364, 1909.

[2] Darton, N. H., Preliminary report on the geology and underground water resources of the central Great Plains: U. S. Geol. Survey Prof. Paper 32, pl. 35, 1905.

the present report is based, while of course not of detailed character, has distinct general value in connecting other areas where geologic work has been or is being carried on.

Regarding the mines and prospects in the two districts described, the report presents reliable statements of facts and conditions which it is hoped may be of use to those specially interested in these deposits.

THE ATLANTIC GOLD DISTRICT, FREMONT COUNTY, WYOMING.

By Arthur C. Spencer.

INTRODUCTION.

In September, 1914, the writer spent three weeks in the vicinity of Atlantic City, in southern Fremont County, Wyo. Although only a short time could be devoted to the study the writer was confronted by the problem of adding to information contained in two excellent reports, one by the late W. C. Knight and the other by L. W. Trumbull, the present State geologist of Wyoming. Prof. Knight has given not only a very adequate description of the general geologic features of the Sweetwater district, which includes the Atlantic district and the Lewiston district (formerly known as the Overland district), lying to the east, but also the results of his own laboratory tests in order to determine the amenability of the gold ores to amalgamation, to chlorination, and to cyanidation. From his observations he was led to make specific suggestions which are of great practical significance. Prof. Trumbull has provided a sketch map upon which the principal geologic features of the Atlantic district are shown.

As it appeared to be impracticable, under the circumstances of inactivity existing, to add materially to the technical data given in Knight's report, the writer decided to turn his attention to making a geologic map of the Atlantic district that should be more detailed than the one presented by Trumbull. In making certain practical suggestions the influence of conclusions drawn by the geologists already referred to is acknowledged.

SITUATION AND GENERAL FEATURES.

Atlantic City is in Fremont County, Wyo., 23 miles due south of Lander, or about 28 miles by wagon road. Lander is the terminus of the Wyoming & Northwestern Railway which connects with the Chicago & Northwestern Railway at Casper. The elevation at Lander is 5,360 feet; at Atlantic City, 7,683 feet; at South Pass City, 7,803 feet. The name Atlantic district is used in this report for the region about Atlantic City, including the environs of South Pass City, 4 miles southwest, and of Miners Delight, 3½ miles northeast.

The Atlantic district and the larger Sweetwater gold country, of which it forms a part geologically, lies entirely within the Missouri River basin, South Pass, on the Continental Divide, being about 10 miles southwest of South Pass City. (See figs. 1 and 2.) A small part of the district northeast of Atlantic City is drained by Beaver Creek, a tributary of Popo Agie River. The Popo Agie joins Wind River near Riverton to form the northward-flowing Bighorn River, whose waters, collected on the northeast side of the Wind River Range, join those of the Yellowstone in Montana. The remainder of the drainage goes by way of Rock Creek and Willow Creek to Sweetwater

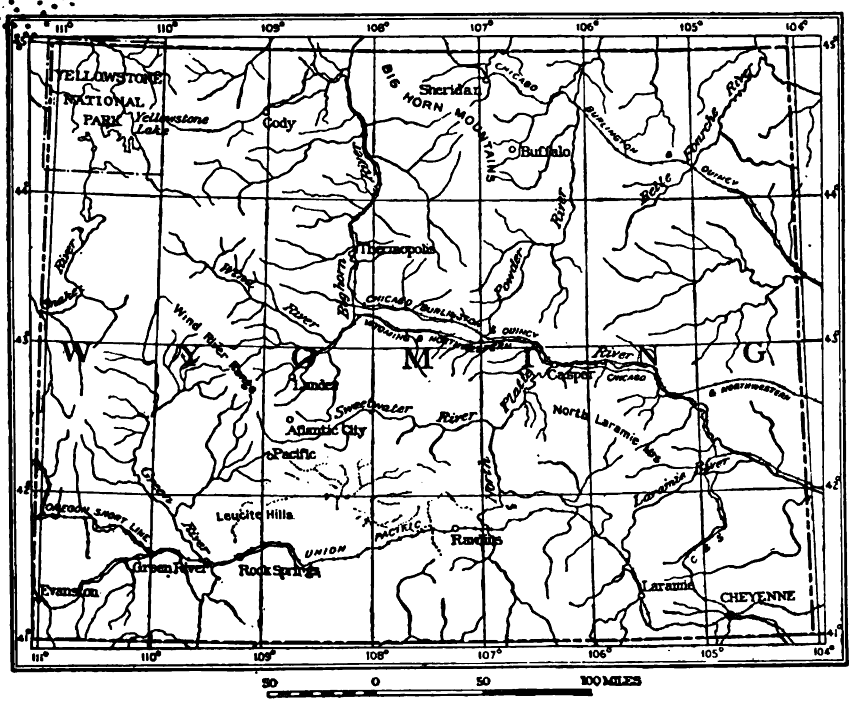


FIGURE 1.—Drainage and railroad map of Wyoming.

River. The upper tributaries of the Sweetwater drain the west side of the Wind River Range as far as a point opposite Lander and the head of the Middle Fork of Popo Agie River, a tributary of the Bighorn system. The Sweetwater flows parallel with the southeastward-trending axis of the Wind River uplift to a point about 10 miles south of South Pass City, where it assumes a more easterly course on its way to join the North Platte. The Sweetwater and Popo Agie headwaters drain the high mountains at the southeast end of the lofty and rugged Wind River Range, which extends for nearly 100 miles to the northwest. Toward the southeast the structural axis of the range may be recognized for a distance of 20 miles, but in this

direction the general elevation gradually decreases and the country becomes less and less rugged. The Atlantic district lies about midway between the high mountains and Sweetwater Valley. Here

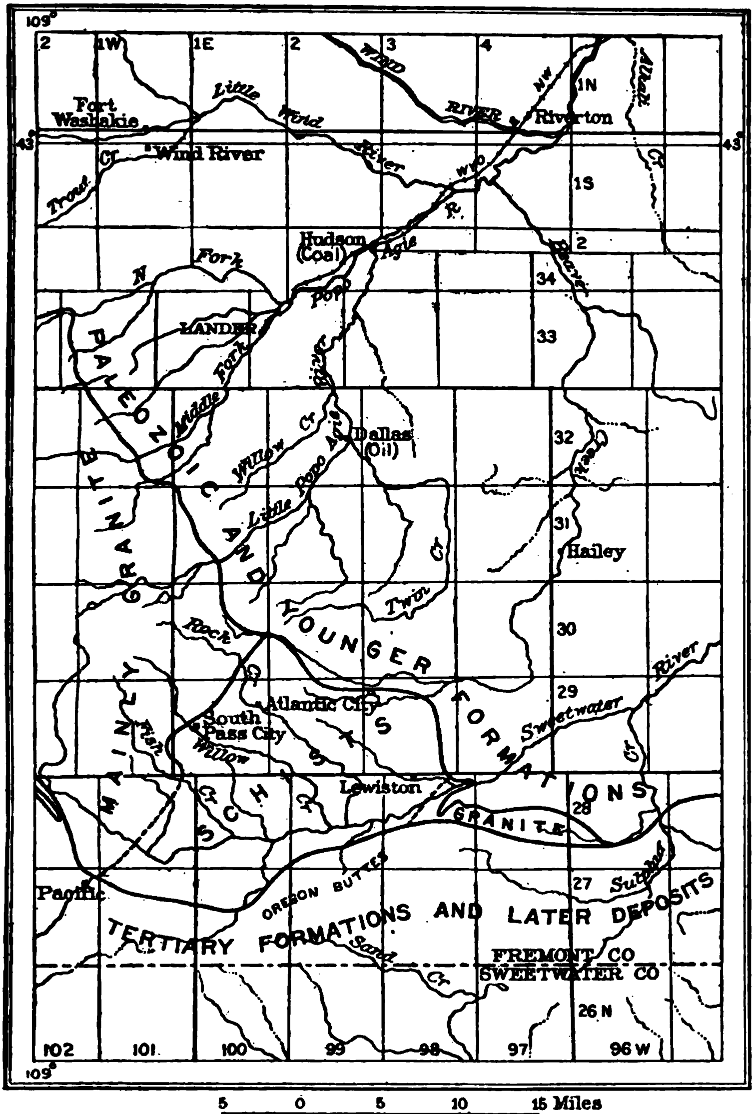


FIGURE 2.—Map of part of Fremont County, Wyo., showing situation of the Atlantic gold district and general geologic features of the region.

Rock Creek has cut a gorge 500 to 600 feet below the height of land on either side, and Willow Creek has excavated a valley from 200 to 500 feet deep. Through erosion along tributary drainage channels the region has come to have a markedly rolling character, but the

impression of a southward-sloping plain, of which the interstream areas form parts, is strikingly presented from points of view south of Atlantic City or from the edge of Willow Creek canyon below South Pass City. Consonant with the southerly slope of the region as a whole nearly all the tributaries both of Rock Creek and of Willow Creek come in from the north. Below Atlantic City the Willow Creek tributaries head practically at the edge of the Rock Creek Canyon.

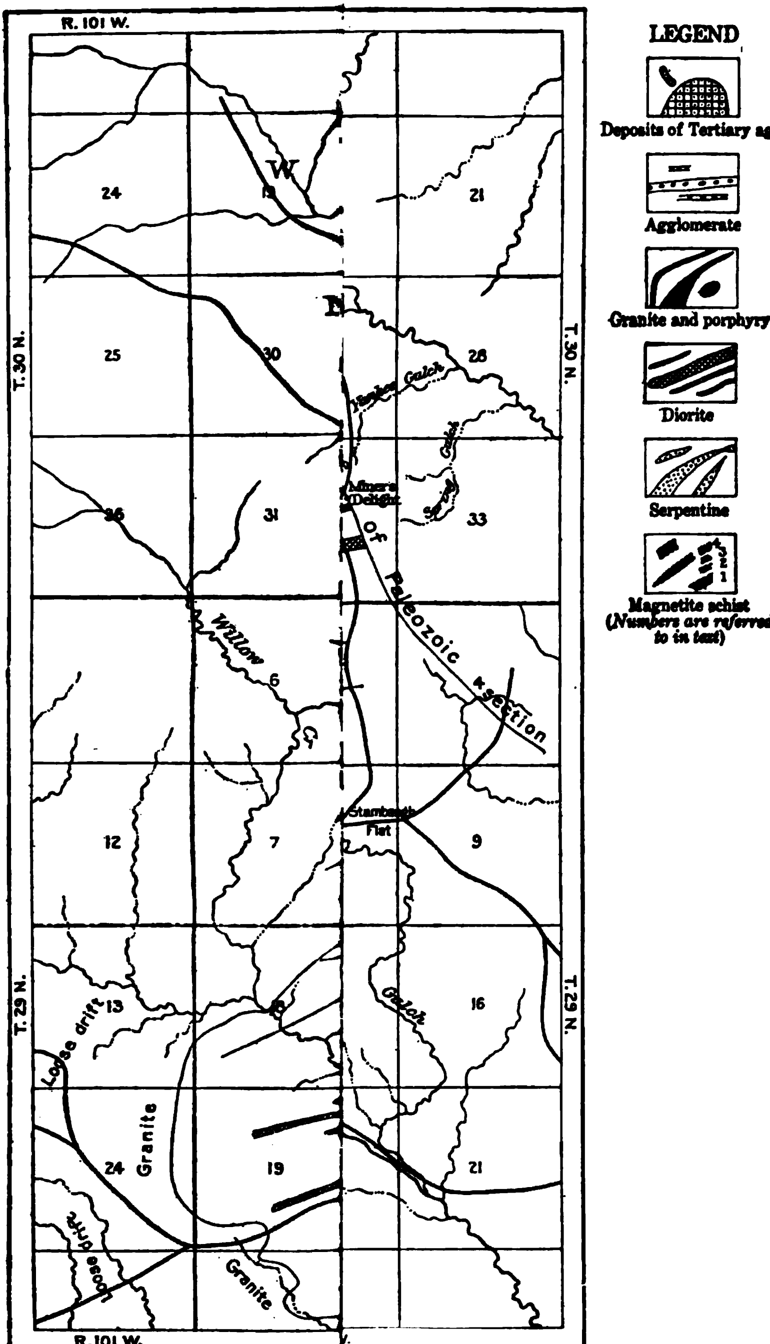
Though the district is one of considerable relief, the slopes are commonly smooth except locally along some of the principal canyons, and almost any point may be easily reached by wagons.

The three principal creeks of the district are perennial streams, the waters of which have been used in a small way for sluice mining and to furnish power for stamp mills. They are not, however, of sufficient volume to be considered alone as of importance in the future development of the district, though if reinforced by waters from Popo Agie River, Rock Creek offers some possibilities.

There is no saw timber in the district, and mine timber is practically lacking, excepting in very small areas, mainly within the Washakie National Forest. Both may be obtained, however, should the need arise, from localities within the national forest 10 to 15 miles to the north. Wood for fuel is hauled from 8 to 12 miles, but only dead wood is obtainable for this purpose, at a cost of \$3.50 to \$5 a cord. Such sparse tree growth as the immediate region originally supported has been greatly depleted, but firewood for prospectors' camps is furnished by aspen, nut pine, and jack pine growing in favored localities. Throughout this foothill region there is an abundant growth of dry-land grasses affording summer range for beef cattle and for sheep. Several hay ranches are profitably operated in irrigable valleys within 10 or 15 miles of Atlantic City, and along the Sweetwater this industry could undoubtedly be extended.

GEOLOGY OF THE GENERAL REGION.

The Wind River range is reported by geologists who have visited it to be composed of granite, granitic gneiss, and hornblende schist. The central line of the range coincides with the northwestward-trending axis of a broad arch along which for more than 100 miles the ancient crystalline rocks have been upthrust and, through the erosion of overlying formations, exposed throughout a zone from 20 to 30 miles wide. (See Pl. I.) Along the southwest side of this zone the crystalline rocks are overlapped by glacial deposits and by formations of Tertiary age that were deposited long after the upthrusting of the arch and after the greater part of the erosion had taken place. Here the flanks of the fold are not generally exposed, but the anticlinal structure is adequately exhibited by the presence of


R. 101 W.
T. 30 N.
T. 29 N.
R. 101 W.
24
19
21
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33
6
12
7
9
13
16
24
19
21
Yankee Gulch
Gulch
Spring
Miners Delight
Willow
Cr.
of Paleozoic section
Stambaugh Flat
Gulch
Loose drift
Granite
Loose drift
Granite
LEGEND
Deposits of Tertiary age
Agglomerate
Granite and porphyry
Diorite
Serpentine
Magnetite schist
(Numbers are referred to in text)
3
2
1

M

Paleozoic rocks where Green River emerges from the mountains, and again at Pacific, about 14 miles southwest of South Pass City. On the northeast stratified rocks ranging in age from Cambrian to late Cretaceous are found tilting away from the high mountains, the harder and more resistant formations forming long hogbacks parallel with the range, and the softer formations appearing along intervening valleys. The Cambrian and younger rocks are in an essentially unmetamorphosed condition. Parallel with the Wind River arch there is a line of elongated domes passing east of Lander. These domes have been prospected for oil with some success.

The manner in which the lower formations of the stratified series rise along the side of the Wind River arch may be seen from Lander. On the way from Lander to Atlantic City, in cliffs on the northeast side of Red Canyon, are seen the basset edges of the red Chugwater formation, and across the valley is a grassy incline which is essentially a dip slope formed by the resistant upper beds of the Embar formation. By climbing to the divide between Red Canyon and Twin Creek and looking back the traveler may see the structure of this side of the arch in diagrammatic clearness. Along the road to the head of Twin Creek lower and lower formations are exposed, and the Cambrian sandstone at the base of the series of noncrystalline formations crops out at Beaver Creek crossing.

Midway between Beaver Creek and Atlantic City, to the east of the mail road, rises Peabody Hill. From the top of this elevation one may look east and see the bold escarpment formed by massive Paleozoic limestones, trending northwest to the divide between Beaver Creek and the Little Popo Agie and southeastward in the direction of Lewiston. To the west are high granite peaks rising above a general platform. This platform, though greatly dissected, appears to merge with the general surface reached by the interstream areas in the foothill region west and southwest from Peabody Hill. As already noted, the surface slopes in a general southerly direction as far as Sweetwater Valley, beyond which the pre-Cambrian rocks are covered by Tertiary formations.

The marked lowering and disappearance of the range between Atlantic Peak and the Sweetwater is, with little doubt, the result of a gentle plunging of the broad anticlinal fold toward the southeast, and the sloping platform that has been described is probably not far below the surface on which the lowest Paleozoic formations were deposited.

From a northeastward-trending line that meets the Paleozoic escarpment north of Beaver Creek southeastward to Lewiston and beyond there are highly metamorphosed rocks, mainly derived from old sediments, that may be grouped under the general term schist. (See fig. 2.) Northwest of this area granite is the principal rock,

and between Lewiston and the point where the Sweetwater breaks through the northeastward-dipping Paleozoic beds granites again appear. A short distance west of South Pass City the schists are broken by coarse red granite, and beyond, near Sweetwater crossing, there are gneisses interlayered with coarse granite or pegmatite.[1]

Knight[2] indicates the existence of two synclinal folds within the sedimentary area, their axes trending somewhat north of east. One of these folds, the axis of which passes north of Atlantic City, has been recognized by the present writer. The axis of the other fold lies about 2 miles north of Lewiston. Except in a very few places the strata are everywhere highly inclined and as a rule they stand nearly vertical. All the prominent folds in the pre-Cambrian rocks trend northeast, or almost directly across the axis of the Wind River anticline.

The occurrence of gold in this region in amounts that have stimulated mining activity appears to be definitely related to the presence of igneous rocks that cut the schists, such intrusions being present both in the Atlantic City and South Pass belt and in the Lewiston district.

GEOLOGY OF THE ATLANTIC DISTRICT.

ROCKS PRESENT.

The rocks occurring in the Atlantic district are crystalline schists derived largely from ancient stratified formations, serpentine, amphibolites representing diorites that have been strongly metamorphosed, quartz porphyry, and granite. The layering in the schists shows persistent northeasterly strikes and steep dips, and bodies of invading igneous rocks conform with this general structure. (See Pl. I.)

SCHISTS.

SCHISTS OF THE CENTRAL ATLANTIC BELT.

The rocks here grouped under the class name schist are in the main strongly metamorphosed sediments, but with these are included certain strongly sheared green rocks, occurring in the northwestern part of the district, that are supposed to have been derived from basic igneous rocks. In the definitely sedimentary portion of the metamorphic complex the rocks appear to have been mainly shales, sandy shales, and fine-grained sandstones, the first two greatly predominating. In places the beds are somewhat calcareous, but no limestone layers have been noted. At several places in the vicinity

[1] Hayden, F. V., U. S. Geol. Survey Terr. Fourth Ann. Rept., p. 38, 1871.

[2] Knight, W. C., The Sweetwater mining district, Fremont County, Wyo.: Wyoming Univ. Geol. Survey Bull., June, 1901.

of Atlantic City and to the north and northeast there are exposures of graphite schist. Near the Rose mine and on the west side of Rock Creek, 1 mile north of Atlantic City, there are sandy beds that carry knots of chiastolite about the size and shape of almond kernels. This rock is known locally as peanut rock.

In addition to the fine-grained sediments, conglomerate occurs along two lines of exposure. Though here called conglomerate this rock may have been originally a volcanic agglomerate or breccia.

The sediments are everywhere in a thoroughly metamorphosed condition. Most of them contain mica as the principal mineral of secondary derivation. In some places a marked cleavage or schistosity is to be noted, but elsewhere the rocks are not greatly sheared, and it is perhaps proper to call such rocks graywackes rather than schists. The conglomerates mentioned above are everywhere greatly mashed, the original rock fragments being flattened so that they form lenses or thin layers that are separated by a felt of hornblende.

STRUCTURE OF THE SCHISTS.

Throughout the schist area the stratification is almost everywhere readily discernible, and in general the sediments are thinly bedded. So far as observed where schistosity is present the secondary structure is parallel with the original bedding.

In the greater part of the district the rock layers stand nearly on edge and the strike ranges from about N. 15° E. to N. 30° E. However, west of South Pass, near the locality where the schists give place to granite, low dips toward the east and northeast were observed, and both on Willow Creek below South Pass City and on Rock Creek below Atlantic City the strata dip to the southeast.

In the area that was most carefully studied the fine-grained sediments, exclusive of the graphite-bearing layers, are all very similar in appearance, and so far as the graywackes are concerned there are no beds or groups of beds that can be followed far enough to make them of any aid in the working out of folds. Below South Pass City, near the mouth of Hermit Gulch, there are massive beds of fine-grained micaceous sandstone that might serve this purpose, but these layers were not traced and corresponding strata were not noted along the canyon of Rock Creek.

Clues that have been found to indicate the structure within the district are, first, a curving boundary convex to the west between the schist area and the granite country northwest, west, and southwest of South Pass City, and low easterly dips in the vicinity of this boundary; second, the two bands of conglomerate occurring north of Atlantic City on the east side of Rock Creek; third, southerly

dips of the rock layers along Willow Creek near the mouth of Hermit Creek and along Rock Creek 2 miles below Atlantic City.

The structure near Atlantic City is essentially isoclinal, in that the rock layers lie nearly parallel among themselves, but the two bands of conglomerate afford very good evidence that the beds are here repeated and that two sides of a fold are represented. The axis of this fold crosses Rock Creek about 1½ miles above Atlantic City and can be traced eastward to the Paleozoic overlap half a mile south of Miners Delight. Toward the west the conglomerate bands have not been identified, and though in this direction the fold is obscure the continuation of its axis would strike the locality west of South Pass City, where the low easterly dips and the curving boundary of the schists against granite indicate the existence of a trough or syncline plunging toward the east. From this correspondence the closely appressed Atlantic fold is regarded as a syncline. The southerly dips observed farther south do not conform with the requirements of a simple syncline but could be explained as the result of a strike fault by which the north side of an adjacent anticline had been cut out. There is a strong presumption that such a fault exists a short distance south of Atlantic City.

If in future studies the conglomerate layer is found south of the Atlantic district, it seems that eventually it will be possible to work out the structure within the area of altered sediments in some detail.

SCHISTS DERIVED FROM IGNEOUS ROCKS.

Northwest of the main area of sedimentary rocks there is a zone occupied principally by green chlorite schists, which, though they have not been closely studied, have probably been derived from some basic igneous rock. Southwestward from the point where it crosses Rock Creek the southern boundary of these schists has been located in a general way, but to the northeast the boundary between the sediments and the green schists was not traced. Southwest of Rock Creek the far boundary of the green schists is against granite that occurs in a band from one-fourth to one-half mile wide. Beyond this granite there is a zone perhaps half a mile wide in which granites and hornblende schists occur in alternation, and to the northwest is massive granite.

From Slate Creek to Beaver Creek the green schists are partly hidden by a deposit of loose rock débris that may be of glacial origin. The covered area is about half a mile in width.

MAGNETITE SCHISTS IN THE NORTHERN PART OF THE DISTRICT.

Distribution and general character.—Northwest of the covered area just referred to is a zone occupied mainly by magnetite, mica, and chlorite schists. These schists are almost completely cut out by

granite west of Rock Creek, but they extend from this place northeastward to and beyond Beaver Creek. Near Rock Creek canyon the zone is about half a mile wide, but toward the Beaver Creek end fully three-fourths of its width is covered by the débris deposits. The schists and accompanying bodies of intrusive diorite stand nearly vertical or dip steeply to the southeast, and the strikes are everywhere northeast. Northwestward across the schists the ferruginous members are succeeded by several hundred feet of shining mica schists. Where exposures are favorable a bed of quartzite from 25 to 50 feet thick is found, and not far beyond this bed there are interlayered schists, granite gneisses, and granite, occupying a zone about 1,000 feet wide.

As only one day could be devoted to a study of this belt it was impossible to map the magnetite schists completely, but from the occurrences that have been plotted on Plate I the conclusion may be fairly drawn that they are distributed throughout a zone about 2,500 feet wide and 2½ miles long. The outcrops north of Beaver Creek were observed only from a distance, but the inference that the iron schists are present in two prominent knolls was confirmed by statements of prospectors familiar with the ground. Here the deposits are capped by the Cambrian sandstone which forms the base of the Paleozoic succession in this region.

In the NW. ¼ sec. 25, T. 30 N., R. 100 W., the more southerly exposures show platy magnetite schists that are more than commonly siliceous, and these rocks are interlayered with mica schists. Between these iron-bearing beds and others forming a prominent ridge nearly 1,000 feet to the northwest there are soft mica and chlorite schists. Very prominent exposures of the iron-bearing rock are to be seen along the east rim of Rock Creek canyon in sec. 26 and on the west side of the creek in sec. 35.

The conclusion is reached that here the aggregate width of the magnetite bands is not less than 1,500 feet. Individual layers of iron-bearing rock from 40 to 250 feet wide are separated either by bodies of granular diorite or by chloritic schists which are probably strongly sheared diorites. All the magnetite-bearing rock is very schistose or slaty.

The magnetite schists considered as iron ore.—The occurrence of iron-bearing rock raises the question of the possible economic value of the deposits. Chemical analyses were made of general samples from four of the magnetite bodies that crop out on the ridge east of Rock Creek (marked 1 to 4 on the map, Pl. I). Essentially continuous exposures were found, and samples weighing from 5 to 7 pounds were taken by chipping across the ledges at intervals of about 2 feet. Sample 1 represents about 180 feet of rock; sample 2, 150 feet; sam-

ple 3, 180 feet; and sample 4, 250 feet. The results of the analyses are as follows:

Partial chemical analyses of magnetite schists, Atlantic district, Wyo.

	1	2	3	4
Iron	42	43	38.6	37
Insoluble	42	40	45.8	47
Phosphorus	.037	.030	.020	.031

Rock carrying from 37 to 43 per cent of iron and from 40 to 47 per cent of insoluble matter can not be profitably smelted, and the conclusion is drawn that material of this grade could be utilized only by submitting it to some process of concentration. In general the magnetite rock is very fine grained, dense, and hard. Crushing would be expensive, as extremely fine crushing would be necessary in order to free the grains of magnetite from those of the siliceous minerals. It therefore seems that the rock would not be readily amenable to concentration.

The siliceous impurities in specimens of the best appearance are pyroxene, hornblende, or chlorite, and in lower-grade materials jaspery silica was noted. In some of the rock the jasper occurs in layers, no more than a few hundredths of an inch thick, but elsewhere the layers of siliceous matter may be as wide as one's finger. Minute seams of limonite, which are of rather common occurrence, indicate the former presence of pyrite, so that the unweathered rock will doubtless contain a small amount of sulphur.

The fact that in taking the samples mentioned above there was no selection as between materials of better or poorer appearance leaves room for the possibility that there may be layers of the iron-bearing rock which contain 50 per cent or more of iron and which could be separately mined. It is believed that this point is worthy of further investigation. If the existence of no more than 5,000,000 or 6,000,000 tons[1] of iron ore fit for the blast furnace without preliminary treatment could be established, the district would be placed in a very favorable situation with respect to proposed railroad extensions.

SERPENTINE AND ASBESTOS.

Four bodies of serpentine are shown on the accompanying map (Pl. I). The serpentine body occurring in the southwest corner of sec. 34, T. 30 N., R. 100 W., has not been prospected, or at least no pits have been dug in it, but along the other bodies asbestos claims have been located and some prospecting has been done. Nothing of any promise was noted either at pits near the east side of sec. 34

[1] Allowing for a specific density of 4, a body of 50 per cent iron ore 10 feet wide and 1,000 feet long would contain 125,000 tons for each 100 feet in depth.

or at others in the NE. ¼ NE. ¼ sec. 26. In the fourth and largest mass of serpentine pits have been opened at several points, and during the summer of 1914 prospecting by William Brice, of Lander, disclosed some very good asbestos. The workings are still very shallow, so that much of the material shows deterioration due to weathering. This is particularly true at one locality where fiber more than 1 inch in length occurs in considerable amounts. Both the altered and the entirely fresh mineral has the softness which is a characteristic of high-grade asbestos and if worked up between the teeth forms a felt free from grit. The greater part of the asbestos thus far found shows fibers less than half an inch long, and commonly seams of such material are closely spaced so that they form veins from 1 to 2 inches wide. A favorable feature of this locality is the fact that immediately to the north there are intrusive masses of granite [1] younger than the serpentine.

INTRUSIVE ROCKS.

DIORITE.

The most abundant intrusive rocks occurring within the general area of the metamorphosed sediments now appear as amphibolite. This name is commonly used to include hornblende-bearing rocks in which the hornblende (and in many rocks other essential mineral constituents) has been formed as the result of a thorough metamorphism of basic igneous rocks. It is often impossible to determine whether the original rock was gabbro, diabase, or diorite. The mineral composition of rocks of this sort occurring in the Atlantic district is like that of diorite, and it will be convenient to use this name for them. These diorites occur as relatively long and narrow dikes following the general structure of the rocks which they invade. Several of these dikes occur in the magnetite schist area 3 miles north of Atlantic City, and they are prominently developed in the strip of country, about 2 miles wide, which contains the principal gold deposits of the Atlantic district. Precisely similar rocks occur also in the Lewiston district.

In the Atlantic gold belt a beginning has been made in mapping the diorite intrusions, with the result shown on the sketch map appearing as Plate I. It is probably correct to assume that all the rock was originally essentially alike, but as a result of differing degrees and kinds of alteration it now presents many varieties. Some of it is entirely massive, the hornblende appearing in irregular but compact individuals. From such material there is a gradation through essentially even-granular rock carrying sheaf-like forms of hornblende

[1] Diller, J. S., The types, modes of occurrence, and important deposits of asbestos in the United States: U. S. Geol. Survey Bull. 470, p. 515, 1910.

to schist in which the hornblende is all fibrous. Locally the rock is still further altered to chlorite schist, and in places where metamorphism has been extreme all semblance to an ordinary igneous rock is lost. The chloritic phases usually have a bright-green color, especially where the rock is eminently schistose; the various hornblende phases range in color from dark green to nearly black.

The dikes that have been mapped range from 50 to more than 400 feet in width. Some of them have been followed individually for distances of a mile or more, and one was found to be continuous throughout a length of 5 miles.

The longest dike of diorite lies about 1,500 feet north of the axis of the Atlantic syncline, and in a nearly symmetrical position to the south there are multiple dikes throughout a zone from 1,000 to 1,500 feet wide that extends in a direction east and somewhat north from Rock Creek to the Paleozoic overlap near the head of little Beaver Creek. The approximate symmetry of these intrusions with respect to the axis of the fold is established by the presence of the conglomerate beds at several points along a line north of and nearly parallel with the northern dike and along the south side of the southern dike zone. The northern dike, which may be called the Gold Dollar dike, from the circumstance that it crosses the group of mining claims bearing that name, has a width of 300 feet or more toward the east, but west of Big Atlantic Gulch it is nowhere more than 100 feet wide. Near the point where it crosses Wood Gulch its course changes from west-southwest to nearly south. Though it appears to terminate in the high hill 2 miles west of Atlantic City, it may continue farther south, but in that direction there are very few rock exposures. The curving of this dike and of the parallel porphyry dike just to the north suggests a corresponding bending of the inclosing strata, but in its long southerly extensions the porphyry dike probably breaks across the stratified rocks. The southern dike zone does not continue directly across the Rock Creek valley but here is offset as if displaced by a nearly east-west fault having a horizontal thrust eastward on the south side. Fairly good evidence that such a fault exists is found in the occurrence of chiastolite graywacke, or "peanut rock," north of the dike zone near the Rose shaft, and in a corresponding position with reference to the diorite dikes that cross Rock Creek. If the conglomerate beds could be found along the south side of the westerly offset part of the dike zone the presence of the supposed fault would be fully established. Because the dikes in the two parts of the zone do not match, the break is believed to have occurred before the intrusion of the igneous rock.

A third zone of diorite intrusions lies just south of Atlantic City and extends westward and southward to and beyond South Pass

City. In this zone there are three principal dikes arranged in overlapping positions. The dike that crosses Rock Creek below Atlantic City may be called the St. Louis dike. It was traced to the northeast only as far as Big Atlantic Gulch. Southwest of Atlantic City and just west of the St. Louis claim it terminates. A short distance to the north, on the Tabor Grand claim, is the eastern end of the Duncan dike, which has an average width of nearly 500 feet and was traced westward to Little Hermit Creek, a distance somewhat greater than 2 miles. West of the point where the mail road crosses Big Hermit Creek there is a large body of diorite that is believed to be connected with the Duncan dike. South of and overlapping the Duncan dike for at least 1 mile is the Carissa dike, which was traced for a distance of 3 miles. It probably extends farther east than is indicated on the map. Where this dike crosses Willow Creek it is about 140 feet wide. Its south wall lies 130 feet north of the Carissa shaft, and here it is more than 150 feet wide. In this vicinity the rock of the dike is a greatly contorted chlorite schist. Farther east parts of the dike are green and schistose and other parts black and massive. The country lying north and northeast of South Pass City was not studied in detail, but two diorite dikes that cross Willow Creek above the Carissa dike have been shown on the map.

DIKES OF PORPHYRY.

In addition to the basic intrusives of the district there are several dikes and small masses of more siliceous igneous rocks, three general types that have been noted being quartz-oligoclase porphyry, orthoclase porphyry, and soda granite.

About 2 miles north of Atlantic City, on the Rustler group of claims, a vertical dike of quartz-oligoclase porphyry is exposed. Its course is a little north of east, parallel with the strike of the inclosing schists. Unweathered specimens obtained from prospect pits show a gray, rather fine grained, apparently even-granular rock, specked with minute grains and small crystals of arsenopyrite and containing pyrrhotite. Under the microscope the texture is seen to be distinctly porphyritic, small crystals of quartz and slightly larger crystals of the oligoclase feldspar being set in a matrix composed of felty sericite. Apparently this sericite replaces an originally glassy groundmass. The same secondary mineral occurs also in some of the feldspar. The introduction of the arsenopyrite and pyrrhotite was obviously contemporaneous with the formation of the sericite. This dike has been traced for about 1 mile, and prospecting at five localities indicates that the rock is everywhere mineralized in the same way. At the outcrop the rock contains cavities

partly filled with limonite, evidently derived mainly from arsenopyrite, and weathered material of this sort is said to carry gold that can be separated by panning.

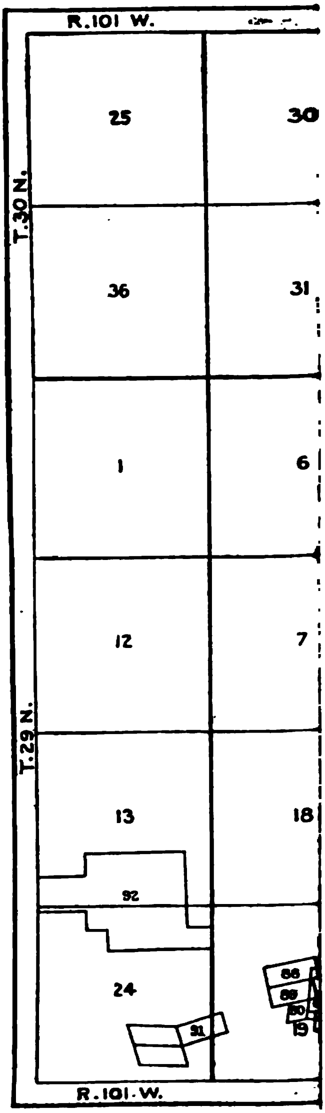
Near Miners Delight there are prominent exposures of a dark blue-gray rock, which, though presenting a general dense appearance, contains abundant lath-shaped crystals of orthoclase. This orthoclase porphyry is known locally as "spotted rock." It occurs in the form of a dike, which has a width of 50 to 150 feet, may be traced 5 miles, and is probably continuous for 6 miles. From Miners Delight its course is at first west-southwest, parallel with a conglomerate bed to the north and with a diorite dike to the south. West of Rock Creek the conglomerate was not recognized. At a point about 1½ miles northwest of Atlantic City the dike curves and assumes a nearly southerly course. Variations in the mineralogic character of the rock are evidently related to differences in the degree of schistosity. At Miners Delight it is distinctly laminated, the groundmass being composed of needles and rods of hornblende. The lath-shaped feldspar crystals lie parallel with the walls of the dike and conformable with the general lamination, but they are not crushed.

Rock similar in general appearance to that of the Miners Delight dike occurs within the south zone of diorite intrusions east of Big Atlantic Gulch and in a larger body west of Atlantic City. In all these occurrences the presence of lath-shaped feldspars is a feature of marked resemblance, but the alterations of the groundmass are different. The rock from the Big Atlantic Gulch locality is schistose, it carries brown mica in the groundmass instead of hornblende, and the feldspar crystals are partly altered to sericite. Rock collected from a point south of the mail road 1½ miles west of Atlantic City shows no marked schistosity, but the groundmass is composed of a felt of hornblende, part of which is altered to chlorite.

MINOR INTRUSIONS OF GRANITE.

Four small masses of granite occur in the zone of diorite dikes that extends south of Atlantic City and north of South Pass City. Three of these granite masses are in or near diorite dikes, as is indicated on the geologic map (Pl. I), and the field relations show that the granite is the younger of the two rocks. The granite is a fine-grained, even-granular gray rock, composed of quartz, oligoclase, and mica. The presence of oligoclase instead of the ordinary orthoclase or microcline of true granite makes the name soda granite appropriate for this rock. In specimens from the Mary Ellen mine the oligoclase is partly altered to sericite.

U. S. GEOLOGICAL SURVEY



1. Dorothy J.
2. Washakie.
3. Arcada.
4. Lone Star.
5. Summit.
6. Peacock.
7. Signal.
8. Central.
9. King.
10. Crown.
11. Paymaster.
12. Minnie B.
13. Fairview.
14. Satila.
15. Oswega.
16. Bonanza 1.
17. Bonanza.
18. Placer.
19. Chicago.
20. Miners Delight.
21. Preserver.
22. Gold Dollar.
23. Milan.
24–26. Gold Dollar group.
27. Ruby Quartz.
28. Snow Bird.
29. Black Bird.
30. Pennsylvania.
31. Augusta C.
32. New York.
33. Blanche May.
34. Cariboo.
35. Arthur.
36. W.J.Bryan(Rose).
37. Garfield.
38. Diana.
39. Lucky Boy.
40. Britannia.
41. Humboldt.
42. Yellowstone.
43. Vulture.
44. West Dip.
45. War Eagle.
46. Ground Hog.
47. Revenue.
48. Cumberland.
49. Hennepin.
50. Ramsay.
51. Rand.
52. Gold Coin.
53. Minneapolis.
54. Denver.
55. St. Louis.
56. Clarissa B.
57. Tabor Grand.
58. Little Nell.
59. Prince Henry.
60. Fair View.
61. Mary Ellen.
62. Cecil Rhodes.
63. Victoria.
64. Duncan Placer.
65. Duncan.
66. Wasp.
67, 68. Silent Friend.
69. Exchange.
70. Dexter 1.
71. Dexter 2.
72. Empire State.
73. Philistine.
74. Rocky Barr.
75. Mars.
76. Mars Pensance.
77. Sampson.
78. Cleveland.
79. Homestake.
80. Lucky Placer.
81. Hermit Placer.
82. Carissa.
83. Mono 2.
84. Jeanette.
85. Lucky Boy.
86. Wolverine.
87. Charles Dickens.
88. Ben Hur.
89. Alpine.
90. J. C. S.
91. Franklin.
92. Wyoming Copper. Co.

MAP SHO

INLIERS OF CAMBRIAN SANDSTONE.

Two small patches of sandstone capping the crystalline rocks were noted—one 2 miles north of Atlantic City in the SE. ¼ sec. 36, T. 30 N., R. 100 W., and the other 2 miles northeast of the town, in the SW. ¼ sec. 5, T. 29 N., R. 99 W. Each of these occurrences is in a swale 50 feet or more below the general hilltop level in the vicinity, and this fact can hardly be interpreted otherwise than as an indication that the basal member of the Paleozoic sedimentary series was deposited on a surface having considerable local relief. The overlap of the Cambrian sandstone along the main outcrop has not been studied.

TERTIARY DEPOSITS.

East of Big Atlantic Gulch, on a broad ridge that separates it from Smith Gulch, there is a deposit of white marly clay. This deposit is regarded as a remnant of the White River formation, of Tertiary age, which is known to occur south of the Sweetwater and which probably was originally deposited over all of the region between that river and the Atlantic district. The deposit consists mainly of a white to yellowish claylike substance that contains only a small amount of carbonate of lime. Such material, though blocky when first excavated, disintegrates or slacks on exposure and is very plastic when wet. Some of the material that carries more calcium carbonate does not disintegrate so readily.

Friable sandstone occurring in the bluffs on the west side of Willow Creek half a mile above South Pass City may also be regarded as a remnant of the White River formation, which in general comprises materials of widely different character.

HISTORICAL NOTES.

The history of gold mining in the Sweetwater district has been related in some detail by Knight,[1] and this account is reprinted in a report by Trumbull.[2] The following summary is based mainly on these reports and on data contained in the reports of Raymond.[3] Plate II shows in part the mining claims in the district.

The discovery of placer gold in the Sweetwater district is said to have been made in 1842. In 1855 a party of 40 men, led by the original discoverer, prospected the region and did some sluicing along Sweetwater River. The leader of the first party returned with eight companions in 1860 and began mining on Strawberry Creek. In the fall of 1861 fifty men had collected at South Pass City with the object

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[1] Knight, W. C., The Sweetwater mining district, Fremont County, Wyo.: Wyoming Univ. Geol. Survey Bull., June, 1901.

[2] Trumbull, L. W., The Atlantic City gold-mining district, Wyoming Geologist's Office Bull. 7, 1914.

[3] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1869, pp. 327-338, 1870; idem for 1871, pp. 374-376, 1873; idem for 1872, p. 306, 1873.

of mining in the following spring, but this party was driven out by Indians and it was not until 1866 that the same leader again returned with a company, which began operations in 1867. On June 8 of that year the Carissa lode was discovered by H. S. Reedall. This third party was driven away by Indians with the loss of three men, but the survivors came back and wintered. By crushing quartz from the lode in a hand mortar and by washing the detritus from the lode they extracted nearly $9,000 in gold. The news of this success spread rapidly, there was a rush to the district, and 500 men went to work. In July, 1869, there were 2,000 people in the district.

The first stamp mill, of six stamps, driven by an overshot water wheel, was erected on Hermit Gulch. It was started July 20, 1868, and up to November 1 had crushed 1,040 tons of ore, yielding an average of $36 currency to the ton. Between April 20 and July 1, 1869, 480 tons of ore, averaging $47 a ton, was treated. The rock crushed came mainly from the Carissa lode, but ore was also hauled from Atlantic City. The second mill, of 10 stamps, driven by a 40-horsepower steam engine, was installed at Miners Delight and between January and July, 1869, is estimated to have extracted more than $60,000 worth of gold from ore taken from the Miners Delight lode. The ore averaged about $40 a ton. The third mill, of 10 stamps, was a steam-power mill at Atlantic City that began operation June 25, 1869. It treated 75 tons of ore from the Soules & Perkins lode at Atlantic City, yielding about $30 a ton.

The principal veins of the district as they are now known were nearly all discovered before 1871, and by that time 12 mills, with a total of 161 stamps, had been erected. Placer work had been done in many places, mainly on Carissa Gulch, a tributary to Willow Creek; on Big Atlantic, Smith, and Promise gulches, tributaries of Rock Creek; along Rock Creek near Atlantic City and on Spring, Yankee, and Meadow gulches, across the Beaver Creek divide. Up to the end of 1873 the gold production of the district appears to have amounted to about $550,000.

In 1872 South Pass City was nearly deserted. The Cariboo and Buckeye mines, near Atlantic City, were being worked, and at Miners Delight three mines were active, but in 1875 the mines of the Sweetwater district were reported as being essentially idle.

After South Pass City, Atlantic City, and Miners Delight had experienced booms and had dwindled to small villages, a fourth camp, Lewiston, was opened, the Burr lode having been discovered in 1879. This camp had a similar experience to that of the others. Knight[1] says:

> Lewiston, like the others, had rich veins of quartz and placer grounds, but the mills have not stamped much ore and the camp is sorely in need of good mining men who

[1] Knight, W. C., op. cit., p. 81.

are willing to develop a mine before they expect it to yield a dividend. * * * The surface ores were quite free and rich, but with depth they rapidly became base and contained iron pyrites and arsenopyrite. The ores extracted near the surface milled easily, but long before the water level was reached the amount of free gold had diminished so that tailings were assaying $35 and $40.

In 1886 the placers on Spring Gulch at Miners Delight were still being worked, though operations were confined to a short season during the spring when water was available.[1]

In 1884 [2] a French company managed by Émile Granier purchased placer claims on Willow, Rock, and Strawberry creeks and began the construction of a canal or ditch to lead the waters of Rock Creek to several points where they could be utilized in hydraulic mining. Before the completion of this ditch, in 1886, plans were made for diverting the water of Christina Lake at the head of Little Popo Agie River, and this project was carried out. The water thus made available was rated at 8,000 miner's inches. A hydraulic elevator, installed on Rock Creek, below Atlantic City, was operated during the three seasons, 1890 to 1892. The total value of the gold recovered is said to have been about $200,000. About 1893 the company became financially embarrassed, and some time afterward its interests were taken over by the Dexter Mining & Milling Co.

The Dexter Co. purchased several undeveloped and partly developed lode claims in addition to the placer ground and water rights of the Granier company. In 1905 the construction of the Dexter Mill at Atlantic City was begun. The Rose tunnel was driven 1,100 feet, but no ore bodies had been developed on any of the company's property in 1914. Trumbull [3] says:

After the completion of the mill, ore was hauled in wagons from various prospects in the district. Twelve thousand tons of $5 to $30 ore were milled and the clean-up gave $6,000 off the plates and absolutely nothing from the cyanide plant.

This administrative and technical failure was followed by bankruptcy and by reorganization as the Timba Bah Mining Co. The affairs of the new company were under the management of a receiver in 1914.

Aside from the activities of the two companies mentioned, interest in the Atlantic district has been maintained largely through recurring attempts to reopen certain of the mines that were most productive during the years 1868 to 1872. Individual prospectors and small associations have been continually at work. Up to about 1906 one or more stamp mills were kept in shape for the use of miners in the treatment of small lots of ore. The advantage of such conditions is obvious, and as there has been lately no reduction plant

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[1] Aughey, Samuel, Wyoming Terr. Geologist Ann. Rept., 1886, p. 12.
[2] Ricketts, L. D., Wyoming Terr. Geologist Ann. Rept., 1888, p. 72.
[3] Trumbull, L. W., op. cit., p. 86.

conveniently available, assessment work has been even more perfunctory than formerly. Among mines that have been taken up at different times, with the idea of systematic development, the most prominent are the Carissa, at South Pass City; the Miners Delight, at the east end of the district; and the Garfield, near Atlantic City.

The Carissa appears to have been idle from about 1873 until 1900 or 1901, when it was acquired by the Federal Gold Mining Co. In 1901 the shaft was sunk to 300 feet and somewhat later to 387 feet, but the depth of the lowest level at present is 360 feet. The recorded production during the period 1902 to 1906 is about 2,800 tons of ore that returned a total in gold and silver of somewhat more than $25,000. The bullion produced was about 0.845 fine. Since 1906 no mining has been done. For several years the mine has been kept free from water, so that the workings might be available for examination. The shaft is 387 feet deep and the workings extend along the vein for about 750 feet. There are five levels, with horizontal workings below the first level amounting to nearly 2,600 feet.

The Miners Delight property appears to have been worked from the time of discovery in 1868 until 1874. It was then idle until about 1880, when the mine was reopened and operated until 1882. In 1893 the property was sold to satisfy a claim of $28,500.[1] A company was formed to begin mining and in 1894 the workings were pumped out. Though a large sum of money is said to have been spent, this attempted revival was not successful. Failure likewise followed work done in 1910 and again in 1913. In both of these attempts comparatively small amounts were expended.

The Garfield claim is supposed by the writer to be the same as an early location known as the Buckeye State. The Buckeye shaft is said to have been 140 feet deep in 1870 and the production at that time was at the rate of $50,000 a year. Several attempts were made to rehabilitate this mine, the most important one in 1891–1894. Two Tremaine stamps and a small hydroelectric plant were installed, but although some gold was produced the returns appear not to have been sufficient to pay for the mine developments that would have been necessary for a financial success. In 1905 the mine, it is reported, yielded $5,000 from 1,000 tons of ore.

The Mary Ellen mine has been another occasional producer, though between 1902 and 1915 the property was involved in litigation.

A recent undertaking has been the development by the Beck Mining Co. of the Duncan mine, 1 mile west of Atlantic City. After an exploration of the Duncan vein by about 1,500 feet of workings four Nissen stamps and amalgamating devices were installed in 1911. The saving of the gold contained in the ore is reported to have been

[1] Eng. and Min. Jour., Dec. 23, 1893.

about 60 per cent, and in 1912 a system of all sliming followed by cyanidation was adopted, with results that are said to have been very satisfactory. Power for the mine and mill and for an electric plant is furnished by internal-combustion engines adapted for burning gasoline or distillate. Mine developments in 1913 and 1914 appear to have been not very encouraging, and it may be that the financial success of this company will depend upon securing control of other mines than the one for which the technically successful extraction process has been worked out.

About 1908 the X. L. Dredging Co. purchased several groups of placer claims in Big Atlantic, Smith, Promise, and Little Beaver gulches and on Stambaugh Flat. In 1912 a ditch and siphon to carry water from upper Rock Creek was completed and some ground was washed on Promise and Smith gulches. In 1914 operations of this company were confined to properties on Beaver Creek.

The Wyoming Copper Co., organized about 1909, obtained a group of claims situated west of Willow Creek about 1 mile above South Pass City and carried on operations at intervals until the summer of 1914. During this period a shaft was opened to a depth of 500 feet and some drifting was done. Small amounts of rich copper minerals were found near the surface, but nothing of value was discovered in the shaft workings, and the project appears to have been finally abandoned in the fall of 1914.

ESTIMATED GOLD PRODUCTION.

Inasmuch as a large part of the gold output of Wyoming has come from the Atlantic and near-by districts, accurate statistics of the gold production of the State, if available, would furnish a very good idea of the progress of mining in the region under consideration. Unfortunately reliable data are not at hand, but figures indicating the gold and silver output have been compiled by the United States Geological Survey,[1] estimates having been made where no definite figures are available.

The value of gold produced in the Atlantic district from 1867 to 1875 is given at $736,100, on the basis of reports by R. W. Raymond. For the years 1876 to 1895, inclusive, the output of the State is estimated at $165,000, and part of this amount was derived from placers in northeastern Wyoming and in the Douglas Creek district. For the years 1896 to 1913 the gold output of the State is given at $290,000, and it is known that a large proportion of the actual output after 1899 came from copper ores.

If the foregoing figures indicating for Wyoming a total gold production of $1,191,178 could be accepted, it would seem probable that the Atlantic district should be credited with an output valued at

[1] Henderson, C. W., U. S. Geol. Survey Mineral Resources, 1913, pt. 1, p. 50, 1914.

less than $1,000,000. Estimates have been published, however, indicating that the production of the district has amounted to more than $5,000,000.

In a footnote Henderson says:

The source of the generally quoted figures ($5,050,000) is W. C. Knight (The mining districts of Wyoming: Wyoming Univ. Agr. College Dept. Bull. 14, October, 1893, pp. 123-124), but Knight says: "The only estimate of the output of this region is one that has been generally circulated, but upon what basis the estimate is made or who is the author I am unable to find out."

The estimate of the gold output of the Atlantic district which is given below is taken from a report on Fremont County published in 1911:[1]

Estimate of gold production of Atlantic district.

LODE MINES.		PLACERS.	
Miners Delight	$1,200,000	Meadow Gulch	$1,000,000
Carissa	1,000,000	Yankee Gulch	500,000
Caribou	500,000	Spring Gulch	30,000
Garfield	400,000	Promise Gulch	30,000
Victoria Regina	350,000	Smith Gulch	20,000
Franklin	300,000	Red Canyon	20,000
Mary Ellen	125,000	Atlantic Gulch	15,000
Lone Star	40,000	Beaver Creek	10,000
Carrie Shields	35,000	Others	150,000
Other quartz mines	187,000		
	4,137,000		1,725,000
			5,862,000

The present writer is inclined to believe that the gold production of the district may have been greater than the indicated total output of the State as given by the Geological Survey figures cited, though it can hardly have been as great as the figure given by Jamison. Possibly the lode mines and placers may have produced as much gold since 1875 as before that year, and if so, a fairly reasonable guess would place the value of the total output at $1,500,000.

VEINS.

PREVIOUS DESCRIPTIONS.

Gold has been found in the bedrock formations mainly in veinlike bodies of quartz which, below the zone of oxidation, carry pyrite or arsenopyrite and in a few places chalcopyrite or galena. The veins have been classified by Knight[2] under four heads—(1) fissure veins that occur in bodies of igneous diorite or granite; (2) contact veins that occur between intrusive rocks and metamorphosed sedimentary

[1] Jamison, C. E., The geology and mineral resources of a portion of Fremont County, Wyo.: Wyoming State Geologist Bull. 2, p. 80, 1911.

[2] Knight, W. C., op. cit., p. 17.

rocks; (3) bedded veins that conform with the dip and strike of the metamorphic schists; and (4) gash veins. Knight says:

The veinstone is quartz. Near the surface is the usual oxidized zone in which the gold is comparatively free. Below this sulphides appear and are of three types—pyrite, arsenopyrite, and galena. Arsenopyrite or pyrite containing a small percentage of arsenic seems to predominate. Occasionally realgar and orpiment are found in minute quantities. No banded structure was found in any of the veins. The quartz is usually massive and varies in color from white to semitransparent with a bluish cast. In the oxidized zone the cavities are filled with limonite. Quartz associated with some of the sulphides usually contains the most of the values. In many instances, however, the schists are especially rich. This condition was especially marked at the Carissa. In the ore stoped it was the rule that the schist clinging to the quartz was gold-bearing, and often there were wires and pellets of gold scattered through the mass. During the last ten years I have assayed schists from this district that contained from 2 to 10 ounces of gold per ton.

Besides the veins, from a foot to 8 or 10 feet wide, that have been opened, there are some mammoth veins of quartz that have been but slightly protected. One of these known as the Mammoth vein is a short distance northeast of Atlantic. It contains some gold, but mines have not been able so far to make it pay. Others of this type are known.

Taken as a whole the veins are of average size, are very persistent, containing good shoots of ore which continue with depth. The relation of the gold contents of these veins with depth could not be worked out.

Trumbull[1] says:

The veins are all quartz filled, and the dip and strike of those carrying workable values show no relation to the strike or dip of the schists. The Big Atlantic and Mammoth veins are heavy wide bands of what seems to be vein quartz, running for miles across the district, following the schists in both dip and strike. But neither of these have shown shoots of pay ore, the gold values being a dollar or less per ton. These leads have been well prospected, for one can follow their course with the eye for miles by the prospect holes dug on them. Their great length and uniform width, also their parallelism with the inclosing schists, make one certain that they are of sedimentary origin.

The gold-bearing veins are found in the schists, diorite, the andesite [called feldspar porphyry in this report], and, in one case, in granite. There is no uniformity of strike. It has been stated that the strike of the veins was in general parallel to that of the schists. In some cases this is true, but apparently it is only a coincidence. The Miners Delight vein, for a part of its length, runs parallel to the strike of the schists, but in other places it strikes nearly across the schists, and the part parallel to the schists has both foot and hanging wall of andesite. Again, the Mary Ellen is a fissure in granite, the strike of which is nearly at right angles to the strike of the schists surrounding the granite intrusion. The veins of the Gold Dollar group and of the Rose strike across the formation, the first in diorite, the second in schist. The Carissa, it is true, does strike parallel to the schists. So also do the several veins of the Garfield. But on the whole there is not evidence to prove that the structure of the schists has controlled the strike or dip of the veins.

The following quotations are taken from a report by Raymond:[2]

The main belt of lodes follows a general northeast and southwest course, but within this limit there is considerable variation in the strike and dip of the veins. Some of

[1] Trumbull, L. W., op. cit., p. 85.

[2] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1869, pp. 329 et seq., 1870.

these ran parallel with the stratification of the country rock; others traverse it at a small angle. The dip of the lodes varies from 50° to 90° and is mostly toward the northwest. Their width varies from 1 to 25 feet. At least one of the walls is generally smooth and well defined, especially when the strike and dip of the vein corresponds with that of the country rock. The walls of the cross veins are mostly imperfectly defined.

The ore of the district is mainly quartz, in which oxide and silicate of iron are finely divided. The dark shade thus imparted to it has caused the miners to call it black iron. Some of the quartz, however, is white and transparent, like that of California. The dark kind of quartz is most common; yellow and red stained varieties are frequently so decomposed that they can be easily crushed between the thumb and forefinger. The miners call this kind sandy quartz and consider it richer than the harder ore.

The bullion is about 0.850 fine in gold on an average.

Base metals, such as lead, zinc, antimony, tellurium, copper, etc., are very rare, and to all appearances the percentage of iron pyrites will be very small, even at greater depth. In a few lodes only, malachite and copper pyrites are found interspersed in the quartz.

The average yield of several thousand tons of ore from different lodes has been from $30 to $40 per ton. The richest ore, yielding $100 and over to the ton, is taken from small lodes with an ore streak of 1 to 2 feet wide; lodes of from 4 to 5 feet wide contain a medium quality of ore, and the long veins of 10 to 25 feet contain a vast amount of low-grade ores. The latter will undoubtedly constitute the main strength and most reliable basis for the mining enterprises of the future.

CLASSIFICATION OF THE VEINS AND OTHER GOLD DEPOSITS.

To the classes of veins enumerated by Knight the present writer adds stringer lodes and certain deposits that are not veins in any strict use of the term but bodies of rock that carry gold associated with disseminated sulphides or arsenopyrite. A convenient classification, which resembles but does not fully conform with the one proposed by Knight, is given in the following paragraphs:

Cross veins.—The class of cross veins is intended to include all veins that strike across or oblique to the general trend of the country rock. It is represented by veins in metamorphosed sedimentary rocks, as at the Rose shaft, on Peabody Hill, and north of Miners Delight; also by veins in igneous rocks, illustrated by the Mary Ellen vein, which occurs in a small body of granite, probably by the Duncan vein, in diorite, and by a vein on the Gold Dollar group of claims, also in diorite.

Strike veins.—The strike veins conform in trend with the strike of the schists, or with the course of inclosing dikes that follow the layers of the schists. The Miners Delight vein occurs in a dike of feldspar porphyry and throughout part of its course is in a general way parallel with the walls of the dike and with a notable though not prominent schistosity of the intrusive rock. Along its outcrop the vein makes a sharp bend from a northeast to a nearly north course, and north of this bend it has the characteristics of a cross vein. Other prominent examples of strike veins are the Lone Star,

Big Atlantic, Mammoth, Cariboo, St. Louis, Tabor Grand, Carrie Shields, and Carissa, and probably the Garfield.

Contrary to the statement of Trumbull quoted on a preceding page, the present writer's observation is that strike veins instead of being rather uncommon are numerous throughout the district.

Stringer lodes.—A group of small quartz bodies interleaved with a schist or reticulating through a massive rock and traceable along a definite course may be called a stringer lode. Typical examples of stringer lodes in schist can not be cited, but in several places and to a noteworthy degree along the Carissa lode it was observed that strike veins show a tendency to lose their solidity and to be continued by a set of multiple veinlets.

Four miles north by west of Atlantic City, about a quarter of a mile north of a point between the two serpentine bodies that flank the magnetite schists, a stringer lode in granite shows a network of veinlets composed mainly of quartz but containing also flesh-colored or reddish orthoclase. Material from shallow prospects on this lode is slightly stained by green copper minerals. Other examples of stringer lodes in granite were noted near the head of Big Hermit Creek. In all these places the lodes have been prospected in a small way, but there are no indications that they contain anything of value.

Gash veins.—The term gash vein is used for quartz fillings that are of very slight extent. In the Atlantic district a few veins of this sort have been found to be very rich in gold.

Mineralized rock masses.—A class which in the Atlantic district may or may not prove to comprise deposits of commercial value is that of rock masses which carry disseminated iron sulphide or arsenide. The most definite illustration of this class that can be cited is a dike of quartz porphyry that is crossed by the mail road about 2 miles north of Atlantic City. This dike traverses the Rustler or Lander Belle group of claims. It is 10 to 20 feet wide and has been traced for a distance of more than a mile. The original rock was a dense rock containing definite crystals of quartz and oligoclase feldspar in an extremely fine grained groundmass. As a result of metamorphism that appears to have affected all parts of the dike, large amounts of sericite have been developed in the groundmass, and the same secondary mineral occurs in some of the feldspar. This sericitization is definite evidence that the alteration of the porphyry was effected by the action of penetrating hot solutions, and these solutions also deposited arsenopyrite and pyrrhotite, which are sparsely but generally disseminated through the mass of the altered rock. In surface exposures the arsenopyrite and pyrrhotite are represented by cavities containing cellular iron oxide and, as such material commonly contains free gold, it is supposed that all the

mineralized rock carries some gold. It is claimed that assays have shown gold to a value of $2.50 to $5 a ton.

An example of altered diorite carrying disseminated pyrite and arsenopyrite was noted in workings on the Ground Hog group of claims, and it is very likely that other deposits of this kind occur in the district.

MINERALOGY OF THE VEINS.

The veins of the district are composed mainly of quartz. At the surface the quartz is likely to be more or less iron-stained, and some of it is cellular and the cavities usually contain yellow, brown, or red limonitic material. As depth increases the amount of limonite diminishes and it becomes evident that this material is derived from pyrite or arsenopyrite. An intermediate product in the decomposition of arsenopyrite is scorodite ($FeAs_4.2H_2O$), which was noted in ore specimens from the Carissa mine.

In addition to the common iron sulphide pyrite, the magnetic sulphide pyrrhotite also occurs, but in general both of these minerals are subordinate in amount to arsenopyrite. A few veins carry chalcopyrite. Galena was observed by the writer only in quartz from the Mary Ellen mine, which also carries a little arsenopyrite.

That the gold contained in the veins is usually associated with the sulphide minerals, including arsenopyrite, is evident from the fact that with increasing depth the ores have proved to be less amenable to amalgamation as a rule.

So-called black quartz, which is of rather common occurrence, carries brown or black tourmaline.

The mineralogy of the veins is in accord with the view held by the writer that the veins are of deep-seated origin, and this view is also supported by the fact that none of the veins show layering or banding, as it is commonly called, parallel with the walls.

GOLD CONTENT OF THE ORES.

Very little definite information can be given concerning the amounts of gold carried by the ores that have been mined from the veins of the district. Notes in Raymond's reports indicate that the ores mined prior to 1872 returned as a rule from $20 to $40 a ton under treatment by stamp milling and simple amalgamation. Some ores were worked that yielded only $15 a ton, and occasional lots yielded as high as $200 a ton. "The average yield of several thousand tons of ore from different lodes has been from $30 to $40 per ton."[1] Among the mines mentioned by Raymond in 1870 are the Carrie Shields, Young America, Carissa, Golden Gate, Wild Irishman, Gold

[1] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1869, p. 330, 1870.

Hunter, Calhoun, Duncan, Mary Ellen, Barnaba, Buckeye State, Soules & Perkins, Cariboo, Miners Delight, and Bennet Line.

Between July 20 and November 1, 1868, the original Hermit mill, near South Pass City, treated 1,040 tons of ore yielding an average of $36 a ton; and between April 20 and July 1, 1869, it crushed 480 tons of ore, averaging $47 a ton.[1]

Ore from the Miners Delight vein is said to have yielded from $16 to $200 a ton, the average having been about $40.

Perusal of old reports relating to the district leaves an impression that many of the lodes occurring in the district might be expected to yield ores carrying on the average as much as $20 a ton. It is believed, however, that as a general rule this expectation will not be realized, though with little doubt shoots of rich ore will be found. It is more likely that assays will show averages of $6 to, say, $15 a ton.

The records of production in possession of the Geological Survey, which are held as confidential with respect to individual mines, indicate that 11,105 tons of ore produced by eight mines since 1902 yielded an average of $8.15 a ton. (See list of assays, p. 40.) On the face of the returns, if a few tons of exceptionally high-grade ore are left out of consideration, the yield appears to have ranged from $5 to $9.18 a ton. The figures given represent the metal recovered, and there is no way of ascertaining the actual gold content of the ores as mined. In so far as gold and silver yields are both given the ratio of gold to silver is found to vary from 5.03 to 10.02, the weighted mean ratio for 8,958 tons of ore being 6.79, which corresponds to a fineness in gold of 0.871.

PROBABLE PERSISTENCE OF THE VEINS.

From a practical man's point of view the first importance naturally attaches to the question whether or not the veins and other gold-bearing deposits of the district will be found to persist to great depth, and if so whether they will continue to carry about the same amounts of gold as near the surface.

In regard to physical persistence, the conclusions may be drawn that these deposits are of deep-seated origin, that the present topographic surface is a chance surface due to erosion, without significant relation to the ore deposits, and that on the whole the deposits must be as abundant at any depth that might be chosen for consideration as they are at the existing surface. Although these general conclusions are fully warranted by the geologic features of the district, they should not be taken as a guaranty that all the veins of the district will be found to be continuous to indefinite depths. It is probable that the lodes showing long outcrops, like the Carissa and Miners Delight,

[1] Raymond, R. W., op. cit., p. 331.

persist to great depths, whereas it would not be surprising if lodes that can be traced at the surface for very short distances are found to pinch out at correspondingly moderate depths. On the whole the writer is inclined to believe that in this district strike veins, if well defined, are likely to prove more persistent than cross veins.

As to the downward continuance of gold content, though it is likely that there has been some enrichment through solution and redeposition in the oxidized portions of the lodes, it is not believed that any really large proportion of the gold in the upper parts of the veins has been secondarily precipitated from surface solutions; and no hesitation is felt in stating the conclusion that the occurrence of valuable ores is not limited to a shallow zone. It may be expected that here, as is the rule in other districts, different parts of the same lode will be found to carry varying amounts of gold, or, in other words, that in any vein the best ore will be found in the form of shoots.

The foregoing conclusions and suggestions indicate the writer's belief that the district is worthy of further development.

FUTURE DEVELOPMENT.

GENERAL OUTLOOK FOR LODE MINING.

In view of the history of the district and its situation 25 miles from railroad transportation the immediate outlook for a general revival of the gold-mining industry is not very encouraging. Nevertheless the writer shares the opinion which has been expressed by several geologists who have made reports on the district, that the early promise of the region may yet be fulfilled. This opinion rests on the belief that the stronger gold-bearing veins of the district persist in depth, with about the same characteristics as they show near the surface. The whole problem, however, involves more than this and requires a consideration of the planning and execution of development work, methods of ore treatment, transportation, and the cost of power. These questions are discussed in the following paragraphs.

PLANNING OF DEVELOPMENT WORK.

In reviewing attempts that have been made either to rework the old mines or to open new ones the fact becomes apparent that the usual procedure has been to install metallurgic plants before they were warranted by developed ore reserves. A plausible justification for this method of attack is that by means of it ore removed during exploratory work can be treated and the proceeds applied to current expenses, thus decreasing the amount of capital required to place an enterprise upon a profitable basis. But this reasoning has proved to be unsound in thousands of instances throughout the gold-mining districts of the United States, and for the Atlantic district the policy

has been ruinous. An important advantage of the method of applying all expenditures at the start to exploration underground is that the enterprise may be abandoned at any stage without incurring what might otherwise become a double or even a quadruple loss. The conclusion can not be too strongly urged that except under unusual circumstances mine development must precede the erection of ore-treating plants if lode mining is ever to be revived in the Atlantic district.

One element of the general problem is that in addition to several gold-bearing lodes which are traceable for long distances there are others that show only short outcrops. Suppose that a quartz vein averaging 3 feet in width shows an outcrop 300 feet long, and that a short vein of the kind may pinch out at a depth of 300 feet. The cubic content of the vein then corresponds with about 20,000 tons of rock. Allow 12,000 tons of ore that could be won and an average yield of about $8 a ton, or say $100,000, and the expense of mine development and mill installation and the cost of mining and treatment might very well consume all the possible proceeds. But if two veins of this kind could be developed so as to be served by one mill the venture might be made to show a profit. The foregoing example is introduced as a basis for the suggestion that multiple development might lead to favorable results where the exploration of a single vein might fail.

It is hoped and expected that the placer ground held by the Timba Bah Co. will be developed at an early date, and if this undertaking is carried out with good results the company should be placed in a position to take up a systematic exploration of lodes on the properties which it controls. The plan of developing several lodes simultaneously could be adopted with advantage by this company.

If several active companies were present in the field a demand for power would arise, and, under some cooperative arrangement, it might prove economically feasible to install a hydroelectric plant that would furnish power for preliminary mine developments.

OUTLOOK FOR RAILROAD TRANSPORTATION.

The district has been at a disadvantage because of its remoteness from a railroad. Supplies were formerly hauled 70 miles or more from stations on the Union Pacific Railroad, but since 1906, when the Wyoming & Northwestern Railway was completed to Lander, about 28 miles from Atlantic City, nearly all the traffic has been with that point.. Only 10 miles south of the district is the now abandoned route of the Overland Telegraph and of the Emigrant or Overland Trail, which led from Casper to the Sweetwater, up this valley to South Pass, and thence across the Green River basin on the way to Great Salt Lake or to the Oregon country. When the Union Pacific

Railroad was planned many engineers regarded the Sweetwater route as more favorable than the more southerly route that was adopted, and it is probable that within 10 years either the Northwestern or the Burlington system will seek an entrance to the Green River basin by way of South Pass. With the extension of either of these lines the situation of the Atlantic and Lewiston districts with respect to transportation will be greatly improved. Atlantic City and South Pass City will then be within 12 miles and possibly within 6 miles of the railroad, depending on whether the location is north or south of Sweetwater River. Lewiston will be still nearer. Whatever alignment is chosen for the railroad, good connecting wagon roads with easy and favorably distributed grades can be cheaply constructed and maintained.

COST OF POWER.

If a railroad is constructed through the upper Sweetwater Valley coal will be made available, and at points along the line should not cost more than $3 to $3.50 a ton. If the smaller figure is taken and if the cost of hauling is assumed to be 35 cents a ton-mile, the estimated cost of coal at points 10 miles from the prospective railroad will be $6.50 a ton. For the present the power problem resolves itself into the use of wood for raising steam; the use of gasoline, distillate, or crude oil in engines of the internal-combustion type; and the development of electric energy in small hydroelectric plants.

Wood for fuel can be obtained from the Washakie National Forest by a haul of 5 to 12 miles, at prices of $3.50 to $5 a cord. Under the regulations of the Forest Service only dead timber is available, the use of which is said to be rather unsatisfactory.

The cost of gasoline delivered has been from 17 to 24 cents a gallon and that of distillate somewhat less. When used in small internal-combustion engines, distillate at 20 cents may be compared with good bituminous coal, burned under a boiler, at about $16 a long ton.

With little doubt engines of the Diesel type could be adapted to use the crude oil produced in the Dallas field, which is situated about 16 miles north of Atlantic City. Since 1911 this oil has been going by a pipe line to Lander, but probably its value for developing power in the Atlantic district would be greater than its value for locomotive fuel, which is reported to be 75 cents a barrel. The possibilities of this oil are suggested by a rough calculation which indicates that, allowing for a cost of $1.40 a barrel at the well and a charge of $1 a barrel for transportation, the cost of crude-oil power would correspond approximately with the cost of steam power if coal could be laid down at $5 a long ton. This calculation is based upon 50-horsepower units. The character of the Dallas oil is shown in the following table:[1]

[1] Woodruff, E. G., The Lander oil field, Fremont County, Wyo.: U. S. Geol. Survey Bull. 452, p. 29, 1911.

Analyses of oils from Lander field, Fremont County, Wyo.

Serial No.	Well No.	Depth of well.	Physical properties.			Distillation by Engler's method.							Paraffin.	Asphalt.	Unsaturated hydrocarbons.	
			Gravity at 60° F.		Color.	Begins to boil.	By volume.								Crude.	150-300° C.
			Specific.	Baumé.			To 150° C. (cubic centimeters).	150-300° C. Cubic centimeters.	150-300° C. Specific gravity.	Residuum. Cubic centimeters.	Residuum. Specific gravity.	Total (cubic centimeters).				
		Feet.		°		° *C.*							*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Wyo. 3	3	750	0.9198	22.2	Dark brown	93	2.5	22.0	(a)	(a)	(a)	(a)	(a)	(a)	50.4	(a)
Wyo. 4	2	400	.9126	23.4	do	120	2.0	23.5	0.8041	69.9	0.9543	95.4	0.91	4.02	16.4	4
Wyo. 5	10	825	.9121	23.5	do	93	2.0	21.0	.8067	75.2	.9589	98.2	1.27	5.69	50.8	4
Wyo. 6	11	965	.9126	23.4	do	105	1.5	24.0	.8018	73.9	.9605	99.4	.90	11.04	58.0	4
Wyo. 7	13	697	.9091	24.0	do	108	2.5	23.0	.8047	73.1	.9589	98.6	.62	15.26	50.8	9

a Flask broke during distillation. Water in the oil.

The erection of an electric power plant in the Dallas oil field has been proposed. This project is technically feasible, and the cost of installation would be less than that of a hydroelectric plant on Little Popo Agie River. The transmission line to Atlantic City would be about 17 miles long.

The development of water power at points along Rock Creek would be feasible for about seven months during the year, but from November to March not only is the stream flow small but it is doubtful whether it could be utilized because of troubles due to freezing in the diversion canals. From April to November the minimum flow including the natural waters of Rock Creek and those diverted from Christina Lake would probably not fall below 20 second-feet. With this flow of water approximately 280 horsepower could be developed at each of two sites, one 3 miles above Atlantic City and the other near that place. The upper site is under the ditch of the X. L. Dredging Co. The first right to water is claimed by the Timba Bah Co., but as the stream would be returned to Rock Creek above the headgate of the lower canal of that company it is not evident that these rights would interfere with each other.

The lower power site near Atlantic City is under the main ditch of the Timba Bah Co., which was planned to deliver water for placer mining along Rock Creek. Although this ditch is now in bad condition it must be repaired in order to work the placers, and either in connection with this work or after its completion a power plant could be built.

About half a mile above the headgate of the lower Timba Bah Canal a small hydroelectric plant was installed about 1895 in connection with an attempt to operate the Garfield mine. By means of a ditch approximately 1 mile long a head of about 50 feet is secured. Under this head, with a flow of 20 second-feet, a turbine would develop about 80 horsepower. The estimated minimum flow is based on the inclusion of water diverted from Christina Lake.

So far as the writer is informed those mentioned above comprise all the water powers that could be economically developed within the district. Although, as already intimated, it is not likely that continuous power could be depended on throughout the year, the fact that no expense would be incurred for diversion canals in the two larger schemes may make them worthy of consideration in the planning of the exploration work that must be done if the mines of the district are to be put upon a producing basis.

The installation of a hydroelectric plant on Little Popo Agie River 10 miles north of Atlantic City is regarded as technically feasible. A preliminary permit for the utilization of this power was granted in 1912 to the Beck Mining Co., but the right has since been abandoned. A diversion canal 2½ miles long was planned to deliver water at a point where an effective head of 750 feet would be attained. This

project lies within the Washakie National Forest, and through the courtesy of the Forest Service, the writer has had access to the application of the Beck Mining Co. leading to the permit referred to above. In this application figures are given representing the net horsepower calculated for average discharge per calendar month for parts of 1907 and 1908. For August, 1907, the calculated horsepower was 4,230. There was a gradual decrease until, for December, 1907, the figure was 1,698. For April, 1908, the horsepower figure given was 4,014, for June 17,760, for September 2,970, and for November 3,810. On January 26, 1912, the flow was calculated as capable of furnishing 1,110 horsepower. According to the formula horsepower = head flow × 0.08, these figures indicate that the minimum flow between August and December, 1907, was about 28 second-feet in December, and between April and November, 1908, was about 49 second-feet in September. The indicated flow for January 26, 1912, is 18.5 second-feet.

In 1915 the district engineer of the Forest Service included in a report on certain water-power projects situated on Popo Agie River records of stream gaging in 1914 on Little Popo Agie River at Young's orchard, west of Dallas. These records show in April, 1914, a flow of 62 second-feet, and in the following October 54 second-feet, the latter being the minimum for the seven months, April to November, during which records were kept.

In consideration of the figures given it seems safe to assume for the Little Popo Agie a minimum flow during seven consecutive months of each year of 40 second-feet, corresponding to 2,400 horsepower; during ten months of 25 second-feet, or 1,500 horsepower; and an extreme minimum of 15 second-feet, or 900 horsepower.

In the foregoing calculations no account is taken of any diversion of water from Christina Lake to Rock Creek.

MILLING OF THE ORES.

In general the ores of the Atlantic and Lewiston districts must be treated on the ground, though lots of exceptional value may be shipped to a smelter. Thus far, aside from the operations of the Beck Mining Co. at the Duncan mine, there has been no systematic endeavor in milling to save gold otherwise than by amalgamation. On the whole the percentages of extraction have been low, in the milling of both unoxidized and oxidized ores, and in future operations better though less simple methods will be in general required.

The problems of ore treatment have been discussed by Knight,[1] from whose valuable report the following quotation is made:

> As soon as the quartz ledges in the Sweetwater district had been opened to a depth varying from 10 to 25 feet, stamp mills were ordered. They were large and small,

[1] Knight, W. C., op. cit., pp. 24 et seq.

and early in 1870 there were 10 or 15 mills in operation or nearly completed. On the very outset there were serious complaints as to the refractory nature of the ore, and in one case at least the stamp mill was abandoned and two arrastres erected in its place. The scouring process of the arrastre brightened the gold and made amalgamation more perfect. The bulk of the milling has always been done with stamps of various patterns and weights, but the saving has been very unsatisfactory. For many years I have assayed the tailings from these camps, and they have never carried less than $5 per ton in gold and in the majority of cases they have assayed from $8 to $20 per ton. The early mill men did not save the tailings, or there would have been many valuable dumps to be worked by some of the modern methods. For years stamp mills were condemned in this district and many other contrivances were brought in to take their place. With the exception of the Huntington mill, every other device has utterly failed. At the present time the stamp mill has been reinstated, it having been proven to be the most effectual crushing device, although as a matter of fact there have been serious complications in the free-milling process, owing to the gold being coated and not amalgamating. This has, beyond question, been the source of the greatest loss, but coarse crushing has always claimed more or less of the values.

The results of amalgamation, cyanidation, and chlorination tests made by Knight on samples of ore from the mines of the region are summarized in the appended table:

Results of tests of ore from Atlantic and Lewiston districts.

Mine.	Sample.	Gold.	Amalgamation saving.	Sands assay.	Cyanide tails.	Chlorination saving.
Atlantic City.		*Ounces per ton.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Rose	10 pounds	2.16	0.95	0.108	Trace.	....
Diana	1 sack	1.5	.82	.027	Trace.	65
Garfield	.....do	.99	.92	.072	None.	95
Mars	10 pounds	.92	.94	.955	Trace.	99
Victoria Regia	1 sack	.65	.81	.120	0.025	77
Cariboo	.....do	.61	.78	.130	None.	71
Jim Dyre	8 pounds	.36	.83	.060	Trace.	99
Rustler	1 sack	.171	.94	.012	None.	....
King Solomon	.....do	.162	.62	.060	.01	74
South Pass.						
Carissa	5 pounds	1.24	.80	.250	.041	56
Lewiston.						
Spotted Horse	1 sack	1.86	.79	.400	.180	Poor.
Midget	.....do	.977	.58	.284	.200	13
Mint	.....do	.612	.57	.260	.140	51
Little Bee	.....do	.252	.68	.080	Trace.	99

The following comments on the results obtained in the investigation are made by Knight:

The ore from the Mint mine is typical of the Lewiston ores and shows clearly what the miners have been struggling with. In the ordinary stamp mill the saving has been very much less than in the tests, since the ore was not crushed as fine and there was no scouring device to aid amalgamation. When a quantity of this ore was treated with warm, concentrated hydrochloric acid, then washed and treated by the free-milling process, the tailings assayed only a trace of gold. It is certain that the poor savings made by chlorination and cyanide were due to the coated condition of the gold.

The ore from the Midget mine resembles that from the Mint. Here ordinary amalgamation would mean a saving of less than 40 per cent of the gold, though some scouring device would assist in making a better recovery. It is probable that, after roasting, chlorination would make a better saving than is indicated by any of the tests applied. Ores of this type should be tested by various chlorination processes. If any of them will extract 90 per cent of the gold it would surpass any process that has been applied to these ores thus far.

Crush the ores as fine as you can consistently. This you will have to decide by milling tests. Occasionally capacity must be sacrificed to secure high recovery, but this must not be carried to the extreme. Utilize concentration wherever possible and treat the concentrates with cyanide or chlorination, roasting if necessary. Utilize the cyanide process to handle tailings. Do not store the sands, as any contained sulphides will oxidize and form soluble compounds that must be washed out or neutralized to prevent cyanide losses.

The tests summarized in the table given on page 40 were made for the most part on oxidized ores, but in the main the suggestions offered are applicable to the treatment of unoxidized ores as well. Naturally the amalgamation tests show extractions that are greater than could be obtained in practice with economical working. A relatively low extraction for sulphide ores is indicated by current statements that amalgamation recoveries at the Carissa and Duncan mills have been between 60 and 75 per cent on ores carrying from 0.50 to 0.75 ounce of gold to the ton. Such results are not greatly inferior to those that have been attained in the treatment of unoxidized gold ores in the stamp mills of Clear Creek and Gilpin counties, Colo. In the Colorado mills the sulphides are concentrated and are shipped out and smelted, transportation and smelting charges being both very low. Obviously concentrates valued at $30 or even $60 a ton could not be shipped from the Atlantic district under present conditions, but in planning the treatment of ore consideration might be given to the possible advantage of amalgamation, plus concentration, plus regrinding of concentrate, followed either by amalgamation or by cyanidation. Where the gold occurs mainly in the sulphides the suggested treatment would obviate fine crushing of the ore as a whole.

To one like the present writer, having only a very general knowledge of gold milling, amalgamation supplemented by cyanidation would seem to be as a rule the most satisfactory procedure, but it is of interest to note that in the treatment of unoxidized ore at the Duncan mill in 1913 amalgamation had been entirely abandoned. This mill[1] is equipped with four Nissen stamps. The original plan was to save the gold by inside and outside amalgamation. With clear water and careful working 75 per cent extraction was possible, but the water supply is scanty and when exhaust water from a steam pump was admitted very careful work was required to keep

[1] Trumbull, L. W., op. cit., pp. 96-100 (description of Duncan mill by D. C. Kelso).

the extraction above 60 per cent. Experiments were made wi the idea of crushing in cyanide solution and amalgamating on plat but the method of all sliming and cyanidation without amalgamati was finally adopted. The capacity of the mill is about 30 tons day. For February, 1913, the cost of treatment is given as $2.' a ton, and of this amount $1.19 is charged against gasoline a distillate used for raising power.

The Dexter or Timba Bah mill at Atlantic City is equipped wi 20 stamps of 1,050 pounds each and is provided with apparatus f cyanide treatment. The mill was erected in 1908 but has nev been in regular operation.

The Carissa mill, with 10 stamps of 550 pounds, is provided wi amalgamating devices and Wilfley concentration tables.

At the Mary Ellen mine there is a 5-foot Huntington mill equipp with amalgamating plates.

PLACER DEPOSITS.

The alluvial deposits of the Atlantic and Lewiston districts ha not been studied in a systematic way, so that only a very brief di cussion of this subject can be presented. On Plate III the distrib tion of the gold-bearing gravels is shown in part.

The greater proportion of the alluvial gold thus far produced h been won by means of the pan or rocker or by sluicing in a small wa The richer gravels occurred in shallow drains heading in ground tra ersed by gold-bearing lodes. Placers in such situations were usuall of very small extent, but as a rule the gravels were thin and therefor readily worked. The small streams in several gulches were diverte by ditches, some of them a mile or more long, but operations wer mainly limited to the spring months because of insufficient water a other seasons. Among the small placers that were worked to advantage within the period 1867 to 1872 were those derived from th Carissa lode, near South Pass City; those of Big Atlantic, Smith, and Promise gulches, east of Atlantic City; of Meadow, Yankee, and Spring gulches, near Miners Delight; of the Crows Nest and Dutch Tom flats, to the southeast; and of several localities in the vicinity of Lewiston. The typical gold from these placers was rough and rather coarse, and nuggets weighing as much as 2 ounces were occasionally found.

During recent years there has been a small and sporadic production by individual miners, but in the main the small placers may be regarded as offering little promise for the future.

A small but steady production of gold has been made for several years from gravels occurring in a ravine on the south side of Rock Creek near Atlantic City. The principal workings are on the Babette

property. Here loose material fills the valley to a depth of 10 to 20 feet, forming a deposit from 50 to perhaps 150 feet wide. Apparently the best dirt occurs in bedrock along a definite channel, and the deposit is worked by means of a drift. The stream is small, but a sufficient volume of water for sluicing is made intermittently available by means of a dam.

Although the larger part of the alluvial gold produced during the early years of activity came from small placers occurring in headwater drains, stream placers were also worked in several places. These deposits occur in all the gulches that receive drainage from the mineralized areas, and downstream from these areas gravels occurring along the principal creeks carry more or less gold. Gulches having grades steep enough to permit ready disposal of waste are Hermit Gulch, near South Pass City, and Big Atlantic and Smith gulches, east of Atlantic City. Of these the two last appear to have been the most productive, though because of diminished slope the lower part of Smith Gulch was never worked extensively.

In 1914 the X. L. Dredging Co. completed a ditch to deliver Rock Creek waters into the upper part of Smith Gulch, and here hydraulic operations were carried on for a few weeks. Whether or not the results of this work were satisfactory is unknown to the writer. During the late part of summer and the autumn this company was reported to be washing gravels at a locality on Little Beaver Creek several miles east of Smith Gulch.

The following quotation is taken from a report by Jamison,[1] former State geologist:

> The X. L. Dredging Co. owns 1,680 acres of placer ground on Little Beaver, Smith, Promise, and Big Atlantic gulches and Stambaugh Flat. The company has constructed a ditch from Rock Creek, 7 miles above Atlantic City, to the placers. A large part of the Stambaugh Flat ground is reported to have a gold tenor of $1.40 per cubic yard, while that in the gulches yields $0.50 per yard.

The gravels along Beaver Creek are reported to carry gold all the way to the junction with Popo Agie River northeast of Hudson. A sample representing 3 feet of gravel on a bar half a mile above the mouth of the creek was found by Schrader[2] to contain gold to the amount of six colors to the pan, corresponding to a value of about 33 cents to the cubic yard.

Placer deposits on Willow Creek near South Pass City and on Rock Creek near Atlantic City were worked for the most part before 1876. In both places the valley floors are from 200 to 1,000 feet wide, and in general the gravels are said to be from 5 to 20 feet deep. The Rock Creek operations seem to have been more extensive than those on Wil-

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[1] Jamison, C. E., Geology and mineral resources of Fremont County, Wyo., p. 79, Cheyenne, 1911.

[2] Schrader, F. C., Gold placers on Wind and Bighorn rivers, Wyo.: U. S. Geol. Survey Bull. 580, p. 142, 1914.

low Creek. Because the gravel flat is broad, the stream grade slight, and the gravel bed rather deep, groundsluicing was not generally practicable and the deposits were worked mainly by means of pits sunk to bedrock. Placer workings below Atlantic City are reported to have yielded in 1869 from $3.50 to $12 a day [1] to the man.

After 1876 and until about 1884 little interest was manifested in the Rock Creek placers. In 1884 French capital was brought into the district through the efforts of an engineer named Émile Granier. The following letter from Granier to L. D. Ricketts is quoted from the report of the Wyoming Territorial Geologist for 1886:

> In 1884 I bought from the original locators some placer claims on Willow Creek, Rock Creek, Strawberry Creek, and Sweetwater River, and the next year I commenced digging ditches for the proposed working by those creeks. The ditch is 10.5 miles [2] long, 3 feet wide at the bottom, 6.75 feet wide at the top, 2.5 feet deep, with 10 feet grade to the mile, and can carry 40 feet of water per second. I expected that the ditch would be filled up with water of Rock Creek alone long enough to wash during the whole summer; but Rock Creek was not sufficient, and I had to finish the big ditch that will carry the water of Christina Lake to the head of Rock Creek. This ditch is 6 miles long, 5 feet wide at the bottom, 11 feet wide at water line, and 3 feet deep and 16 feet grade per mile, and can carry 144 feet of water per second. It was cut through solid granite rock for more than half of the way. It has a flume, on trestles 70 feet high and 500 feet long, 6 feet wide and 4 feet high.
>
> Christina Lake is about 1½ miles long, and it is situated at the foot of Atlantic Peak, at 10,000 feet above the level of the sea.
>
> I intend to wash the Rock Creek bottom with one of Joshua Hendy's hydraulic elevators, because the grade of the creek is so small that it is impossible to wash off the tailings. It is not yet quite certain that this machine will work well.

This plant was operated during the three seasons 1890 to 1892 at a point about 2 miles below Atlantic City. A large amount of gravel was moved, but although the value of the gold produced is reported to have been about $200,000, the operations of the Christina Lake Co. ceased in 1892.

The following is quoted from Knight: [3]

> Special mention should be made of Rock Creek, from Atlantic for a distance of 4 miles below. The gulch is quite narrow, the fall slight, bedrock rough and covered with 5 to 10 feet of gravel. The gold is coarse and is found upon bedrock. This ground lies just below the gold-bearing zone and has been prospected by pits and found to be very rich. Originally a Hendy hydraulic elevator was put in to handle the tailings, but for some reason it failed. Only a couple of years ago [that is, about 1899] a steam shovel was put in to handle the gravel, and on this occasion the failure was due to lack of water. I do not know of any absolute figures relating to the value of the property per cubic yard, but I am convinced that it is sufficiently rich to warrant the installation of a modern plant that will handle the gravel successfully and pay handsome dividend upon the investment.

[1] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1869, p. 337, 1870.

[2] Actually constructed, about 5 miles.—A. C. S.

[3] Knight, W. C., The Sweetwater mining district, Fremont County, Wyo.: Wyoming Univ. Geol. Survey Bull., June, 1901, p. 23.

The only locality on Sweetwater River that was visited by the writer lies immediately south of Lewiston. Here a gravel deposit forms a flat half a mile or more long. Gold in the form of minute flakes was found in nearly all of several lots of dirt that were panned. These samples were taken practically at the surface. The deposit is about 6 miles below the mouth of Rock Creek and by its position must have received wash from both the Atlantic and the Lewiston lode zones.

It is considered that systematic sampling of this placer is warranted and the suggestion is made that this could best be done by means of churn drills. An adequate number of test shafts would be very expensive, work already done having shown that in sinking to bedrock pumps of large capacity are required.

The occurrence of placer gold along Red Canyon (see Pl. III) is worthy of passing mention because at one time the deposits were made the basis of a rather remarkable promoting exploit. Certain capitalists were induced to form a company and to buy up all the lands along the creek bottom, most of which were owned by prosperous ranchers. Although the ground is commonly regarded as valueless for mining, the ranches are all tenanted, garden truck, fruit, and alfalfa are raised, sheep are wintered, and the venture appears to have been financially successful. The uppermost farm, known as the Tweed ranch, is served by a ditch from Twin Creek. Adjacent to this ditch and visible from the wagon road there are old placer workings at several points. A general cover of gravel appears on the broad ridge that forms the divide between Red Canyon and Twin Creek, and it is obvious that the locally concentrated gold has been derived from this deposit. The bedrock formations are limestone and sandstones, but the gravel is composed almost entirely of crystalline rocks which must have come from the Wind River Range, a considerable distance west of the present headwaters of Red Canyon and Twin creeks. Perched high above the beds of the nearest streams and separated as they now are from the area of pre-Cambrian crystalline rocks by intervening canyons, these gravel beds point to marked drainage changes in recent geologic time—changes whose interpretation can not be attempted until the erosional history of the general region has been studied in detail.

ECONOMIC GEOLOGY OF THE NORTH LARAMIE MOUNTAINS, CONVERSE AND ALBANY COUNTIES, WYOMING.

By Arthur C. Spencer.

INTRODUCTION.

During August, 1914, the writer visited all the better-known localities in southern Converse County and the northern tier of townships in Albany County, Wyo., where prospecting for metalliferous ores has been carried on at various times during the last 30 or 40 years. Most of the work has been done in the search for copper, but at one locality lead ores have been opened, at another chromic iron ore, and at another magnetic iron ore. With one exception all the mineral occurrences that were examined are associated with rocks of pre-Cambrian age. which constitute the core of the Laramie Mountains.

The writer was fortunate in having as guide and companion Mr. W. F. Mecum, of Douglas, Wyo., whose familiarity with the region made it possible to visit many widely separated localities in the comparatively short space of three weeks.

NORTH LARAMIE MOUNTAINS.

Definition.—The Laramie Mountains are the continuation into Wyoming of the Front Range of Colorado. Lying between the Great Plains on the east and the Laramie Basin on the west the range, from 10 to 25 miles wide, trends north from the State boundary to Laramie Peak, a distance of 85 miles, thence northwest for about 50 miles, where its characteristic features are lost in the vicinity of Casper. Parts of the range near Casper have received distinctive names, being known as the Casper, Haystack, and Deer Creek ranges. The following notes relate only to the northern part of the range.

Configuration.—The topography of the range is in general rugged, but the upper valleys of some of the streams are rather broad, and there are many interstream areas that are fairly smooth. Locally along the water parting such areas merge to form rolling uplands of considerable extent. Above these comparatively smooth areas rise the higher mountains and below them, along the lower courses of the

streams, deep and steep-walled gorges have been excavated. The height of land, as determined both by the principal summits and by the mountain passes, lies well to the southwest of the axis of the range.

Laramie Peak, the culminating summit, reaches an elevation above 10,000 feet, other mountains to the northwest ranging from about 9,000 down to 8,000 feet in height, and near the end of the range down to about 7,000 feet. The principal defiles are at elevations of 7,000 to 8,000 feet. Except in the vicinity of Laramie Peak the roughest part of this northern section of the range is along a zone lying a short distance back of the curving edge of the area of crystalline rocks which faces northeast and north. Here the streams commonly flow in narrow canyons from 500 to 700 feet or more in depth; and as the gorges are rather closely spaced the topography is extremely rough.

Drainage.—North Platte River flows nearly due north from its source west of the Medicine Bow Mountains in North Park, Colo., for about 100 miles to the mouth of Sweetwater River, where it turns to sweep in a great curve around the northwest end of the Laramie Range to Casper, thence flows east to Douglas and southeastward across the High Plains of Wyoming and Nebraska. Thus the northern part of the Laramie Range is drained on both sides by tributaries of the North Platte—on the southwest by headwater streams of Medicine Bow River and on the west, north, and east by creeks that flow directly to the master stream.

The drainage pattern is distinctly asymmetric, the divide between streams that flow south or southwest and those that flow north, northeast, or east being situated southeast of the axis of the mountainous belt.

Climate.—The average yearly precipitation within the northern part of the Laramie Range is probably about 20 inches, or perhaps somewhat more than 50 per cent above that on the plains to the east and double that on the Laramie Plains. This figure is an estimate based on the general character of vegetation and on the distribution of floral assemblages. At Lusk, on the high plains in southeastern Converse County, the annual precipitation is about 13 inches; at Fort Laramie, 50 miles south of Lusk, about 11 inches; and at Laramie about 10 inches. Meteorologic records relating to the stations named show that the spring and summer precipitation is materially greater than that of autumn and winter; but as in the mountains the winter snows commonly accumulate to depths of 2 feet or more it is evident that here the precipitation is more evenly distributed throughout the seasons.

The mean annual temperature at elevations below 6,000 feet is probably about 42° F., the extreme range being from $-35°$ to $+100°$.

Above 6,000 feet the temperatures are of course lower, especially in summer, and frosts may occur during any month in localities at about 7,000 feet.

Vegetation, stock raising, and agriculture.—Like the Great Plains, the foothills and middle slopes of the Laramie Mountains are clothed with grasses, growth of which is especially luxuriant between elevations of 5,000 and 7,000 feet, or locally even up to 8,000 feet. Grass and sagebrush grow together on ridge slopes up to 6,500 feet and locally at higher elevations, but ridges and many extensive areas above this level are covered by grass alone. This region, in common with Wyoming as a whole, supports an extensive grazing industry. Horses, beef cattle, and sheep range through the mountains from May until late in September, when they are moved to valley ranches or to winter ranges on the surrounding plains.

Dry-land farming is carried on, though perhaps in general not with signal success, in smooth areas up to elevations of 7,000 feet, where wheat, oats, and potatoes usually mature during a short growing season and where many garden plants may be successfully grown.

In the broader valleys of the principal creeks, usually below 6,000 feet in elevation, oats, wheat, and forage crops, including alfalfa and timothy, are grown on irrigated ranches. Some of these operations carried on in connection with sheep or cattle raising are on a large scale. Apples, small fruits, and garden truck are also raised. Some of the irrigated lands of the foothill belt utilizing the natural flow of the mountain streams have been under cultivation since about 1880.

On La Prele Creek, about 10 miles east of Douglas, a great dam of concrete now stores the winter waters of this stream for use during the growing season. These works have greatly extended the amount of land irrigable from La Prele Creek, and the dam is so placed that the water may be used for generating electric energy, the use of which is contemplated for pumping water to irrigate lands along the north side of North Platte River west of Douglas. Other projects of the same sort in this region are probably feasible.

A large part of the mountainous area lying above an elevation of 7,000 feet supports a forest growth comprising white and yellow pines suitable for high-class lumber and the less valuable lodgepole and jack pines. Spruce and balsam fir occur but are not abundant, excepting on the slopes of Laramie Peak. Aspen is the principal deciduous tree in the mountains. Cottonwood and the maple-leaved ash or box elder grow along the lower valleys.

At a number of places sawmills have been operated, their product having been sold to ranchers and even at railroad points in competition with lumber from distant points. The better or more accessi-

ble forests have been cut over, so that this industry has greatly declined in recent years.

Railroads.—The region in which the North Laramie Mountains lie is served by four railroads. The southern part of the range is best reached from Medicine Bow station, on the Union Pacific Railroad. East of the mountains is the line of the Colorado & Southern Railway, running north from Cheyenne to Hartville Junction, southeast of Orin. North of the range are the Chicago & Northwestern Railway and the Chicago, Burlington & Quincy Railroad, which run parallel with North Platte River westward from Orin as far as Casper.

Wagon roads.—There are several easy routes north and south or northeast and southwest across the range, along any one of which a good road could be maintained with a moderate expenditure. Formerly there was a stage line from Medicine Bow and Rock Creek stations, on the Union Pacific Railroad, directly north to Fort Fetterman. At present most of the transmountain roads are out of repair, but a fairly good road is maintained through Cold Spring Pass, at the head of La Prele Creek. Routes parallel with the principal creeks are comparatively easy, but travel parallel with the mountain axis is everywhere difficult and in the main impracticable. Still nearly all parts of the region are accessible, though many localities can be reached only by making long detours from the main lines of travel.

From Glendo there is a good road into the district north of Laramie Peak, and this country is also readily accessible from Douglas. Mining prospects in the upper drainage basins of La Bonte and La Prele creeks are most directly reached from Douglas, and localities farther west in Converse County either from Glenrock or from Casper.

GEOLOGY.

GENERAL STRATIGRAPHY AND STRUCTURE.

The Laramie Range as a whole comprises a central belt of pre-Cambrian crystalline rocks flanked on both sides by areas of stratified rocks that range in age from Carboniferous to late Cretaceous and early Tertiary. Later Tertiary formations are also prominent locally, and Quaternary deposits may be recognized at several places just outside of the mountainous belt.

The structure of the range is anticlinal. The older crystalline rocks have been, as it were, pushed up along the axial belt, so that the younger sedimentary rocks dip away from the core on both sides. The nature of the contact between the crystalline rocks and the lowest sedimentary beds shows that the sediments were deposited on a nearly smooth suface. There is no doubt that the Paleozoic and Mesozoic formations, now seen in uptilted positions, once extended

across the area occupied by the mountains, having been since removed by erosion.

On the east and north side of the mountains the sedimentary formations almost everywhere have steep dips, and locally there are strong faults parallel with the general strike. In a few places there are cross faults which produce sharp irregularities in the boundary between sedimentary and crystalline rocks. On the side of the range next to the Laramie Plains the dips are more gentle, so that the profile of the uplift, if restored, would be that of an asymmetric arch with its crest well over toward the convex side of the belt of crystalline rocks. This belt is from 10 to 25 miles wide.

South of Laramie Peak the structure appears to be simple, but toward the northwest the main arch is flanked on the north by a series of minor flexures, almost the whole of the sedimentary series being here sharply but irregularly corrugated, within a zone about 10 miles wide, now characterized by considerable topographic relief. Subsequent to the uplift, which is assigned to the Laramide revolution, erosion was active during a long period, and the general topography of the region came to be very much what it is at present. Toward the end of this erosional period the downstream parts of the main river valleys to the east became clogged with débris, and gradually the deposition of materials derived from the mountains progressed upstream. The stream channels shifted from side to side, so that their deposits eventually merged to form extensive mantles of sedimentary material that covered the former foothills of the range and extended in many places well up on the mountain ridges and along some of the wider valleys quite to the main divide.

In this general region several Tertiary formations ranging in age from Eocene to Miocene have been recognized. The deposits of the Laramie Mountains belong mainly, if not entirely, to the Oligocene White River formation.

After the accumulation of the White River beds the region was one of "buried mountains," all the deeper valleys having been partly filled. Next came a renewal of active erosion. Within the mountains much of the débris was carried away and the streams cut their present valleys. One result of the deep infilling in Tertiary time was the diversion of the larger creeks from their previous courses. When erosion was renewed the new channels were maintained, and where bedrock was encountered narrow canyons were excavated. In places, therefore, the topography is now rougher than it was before the deposition of the White River formation.

The crystalline rocks that form the core of the mountains comprise coarse granite, serpentine, dark schists, and numerous nearly black dikes of diabase. The structural lines in this crystalline area generally trend southwest or transverse to the axis of the range.

THE GEOLOGIC MAP.

The topography of the North Laramie Mountains and the general distribution of the crystalline rocks and sedimentary formations along the range are shown on the accompanying map (Pl. IV). This map is mainly the result of field work done by N. H. Darton and assistants in 1906 and 1907, but in its compilation a map of the Douglas oil field by V. H. Barnett has been used and observations by C. J. Hares and by the present writer have been incorporated.

The short descriptions of the sedimentary formations occurring within the area discussed in this report are written by N. H. Darton, who has previously mapped the area on a smaller scale and parts of it on the same scale. (See pp. 53–56.) The time spent in the region by the writer was very short, and no attempt was made to separate the different crystalline rocks, so that in this connection the map is useful only in showing the general extent of the pre-Cambrian complex.

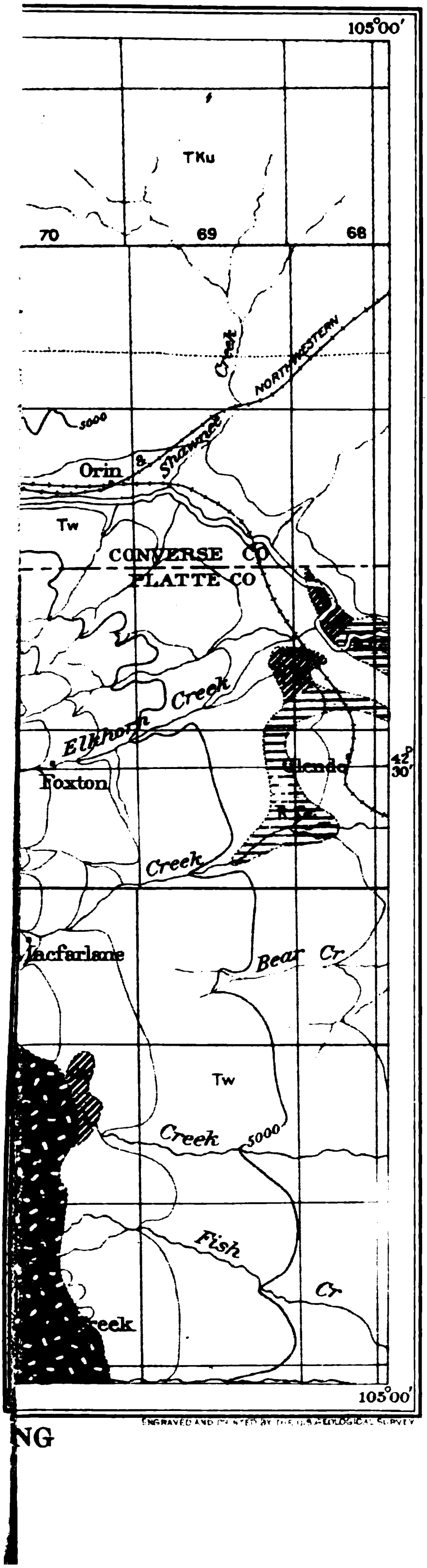
PRE-CAMBRIAN ROCKS.

The complex of crystalline rocks which constitutes the core of the North Laramie Mountains has not been studied in detail, but observations along routes traveled by the writer are sufficient to show the general resemblance of the pre-Cambrian complex here and in other districts to the south and west. The rocks of the Sherman quadrangle,[1] the northern edge of which is about 25 miles south of Laramie Peak, comprise schists and gneisses, which are regarded as in part of sedimentary and in part of igneous origin, and these rocks are interrupted by intrusive bodies of gabbro, syenite, anorthosite, granite, and granite porphyry. There are many narrow dikes of diabase and diorite which cut all the rocks named above. The contacts between the different sorts of rocks commonly trend southwest.

West of the termination of the Laramie Range, in the lower Sweetwater country, the principal rocks of the pre-Cambrian areas are red and gray granites, but there are also bodies of schist, as well as many narrow black or greenish dikes that run in northeast courses.

As in the neighboring regions that have been mentioned, coarse-grained granites are the most abundant rocks in the nucleus or core of the North Laramie Mountains. North of Laramie Peak, in the headwater region of Horseshoe and Elkhorn creeks, there are considerable areas of dark schistose rocks, more or less broken from place to place by intruded masses of granite. The schists trend southwest and the contacts between schists and intrusive rocks are

[1] U. S. Geol. Survey Geol. Atlas, Laramie-Sherman folio (No. 173), 1910.



LEGEND

TERTIARY

Tw — White River formation (Oligocene)

TKu — Undifferentiated Eocene and later Cretaceous, including Fort Union formation at top and Mesaverde formation at base

CRETACEOUS

Ks — Steele shale

Kn — Niobrara shale

Kb — Benton shale

Kc — Cloverly (?) sandstone

JURASSIC OR CRETACEOUS

Morrison formation

JURASSIC

Sundance formation

TRIASSIC (?) AND CARBONIFEROUS

Ћ-Cc — Chugwater formation (Triassic ?) including in places Forelle (?) limestone and Satanka (?) shale, of Pennsylvanian age

CARBONIFEROUS

Casper formation (chiefly Pennsylvanian)

PRE-CAMBRIAN

gr — Granite, gneiss, etc.

Fault

Area along north side of Casper Range shown is Chugwater formation (Ћ-Cc) should be shown as granite, gneiss, etc.

as a rule steeply inclined or nearly vertical. The writer's impression of these highly metamorphosed rocks is that they represent a series of interlayered sediments and volcanic rocks. Schists like those occurring in the eastern part of the region were not noted in traveling by a circuitous route from Spring Hill post office centrally along the range to Boxelder Creek. Hornblende schist was seen, however, on the south side of the range along the Converse-Albany line in R. 76 W., and the same rock is reported to occur in the high mountains at the head of Boxelder Creek. Throughout the middle section of the range coarse grained gray and red granites abound, and in the main they are interrupted only by narrow dikes of diabase.

Pegmatites, which are particularly coarse grained phases of the granite, occur in relatively small masses in all parts of the district.

In the western part of the range the granites predominate to a less degree and dark schists occur in many places. Locally these rocks inclose masses of serpentine, a metamorphic igneous rock older than the granites. In Natrona County, west of the area visited, the serpentine contains asbestos deposits which have been under development for several years and which it is hoped will prove to be of industrial importance.

SEDIMENTARY ROCKS.

By N. H. Darton.

GENERAL FEATURES.

The sedimentary rocks[1] on the north slope of the Laramie Mountains comprise strata from Carboniferous to early Tertiary in age. The succession appears to be conformable, but not all the geologic epochs are fully represented. The principal gaps are part of the Jurassic and probably much, if not all, of the Triassic. The Tertiary is represented by some of its earlier deposits in conformable sequence and also by the White River formation, which overlaps the other formations and in places lies on the granites and schists.

CARBONIFEROUS SYSTEM.

Casper formation.—The granites, schists, and other crystalline rocks of the Laramie Mountains are overlain by the sandstones and limestones of the Casper formation, whose thickness ranges from 400 to 700 feet. The maximum thickness is shown on La Bonte Creek a mile northwest of Spring Hill. A basal sandstone or quartzite, in most places conglomeratic, is 60 to 100 feet thick in the western

[1] These rocks are described by N. H. Darton (Paleozoic and Mesozoic of central Wyoming: Geol. Soc. America Bull., vol. 19, pp. 403–470, pls. 21–30, 1908), and the upper beds also by V. H. Barnett (Possibilities of oil in the Big Muddy dome: U. S. Geol. Survey Bull. 581, pp. 105–117, 1914; The Douglas oil and gas field: U. S. Geol. Survey Bull. 541, pp. 49–88, pl. 4, 1914).

part of the region but thins toward the east, so that in slopes west and south of Douglas the limestones are not far above the crystalline rocks. These limestones are light gray and from 200 to 500 feet thick. They are overlain by a hard gray massive sandstone which constitutes most of the mountain slopes. Extensive exposures occur in Muddy, Deer, Boxelder, and La Prele canyons. In La Prele Canyon the strata are flexed in a fine arch and the upper sandstone constitutes a well-known natural bridge. The sandstone is massive, coarse grained, and usually light colored, but in some of the ridges west of Douglas it weathers dark brown. It probably represents the Tensleep sandstone of the region farther north.

Fossils are not often found in the Casper beds, but those obtained indicate that while the formation belongs mainly in the Pennsylvanian series possibly the basal beds may be Mississippian.

Satanka (?) shale and Forelle (?) limestone.—The sandstone at the top of the Casper formation is overlain by 50 to 80 feet of red shale and this in turn by 20 to 30 feet of limestone. These beds are supposed to represent the Satanka shale and Forelle limestone of the Laramie Basin or the Opeche formation and Minnekahta limestone of the Black Hills in South Dakota. They crop out along the south side of the Casper Range, on the north slope of the Deer Creek Range, on La Prele Creek south of Inez, in the uplifts east and southeast of Beaver, and on the west side of the Laramie Mountains. A small outcrop of the limestone lying on 50 feet of shale appears in the bank of North Platte River 7 miles south of Douglas.

TRIASSIC (?) SYSTEM.

Chugwater formation.—The red shales and sandstones of the Chugwater formation crop out on the south side of the Casper Range, on both slopes of the Haystack Range, on the north side of the Deer Creek Range, in the several small uplifts south of Douglas, in the ridge east of Freeland, and along the west side of the Laramie Range near Marshall and Little Medicine. They probably underlie the White River formation in part of the valley about Beaver and southwest of Inez. The thickness of the formation averages about 1,200 feet, but on La Prele Creek it has been estimated at 1,500 feet. Thin beds of limestone and gypsum are included at some localities, notably at the east end of the Casper Range and north of Freeland.

JURASSIC SYSTEM.

Sundance formation.—The Sundance formation is exposed in narrow zones of outcrop adjoining those of the Chugwater formation mentioned above. The most extensive exposures are in the uplifts south of Douglas and near Freeland. The thickness of the formation

ranges from 200 to 300 feet. The basal beds consist largely of buff to reddish sandstones, and the upper beds are made up of 150 to 200 feet of gray shale with thin layers of limestone filled with characteristic fossils of Jurassic age. The shales are mostly dark gray and fissile, and therefore differ in character from the Morrison deposits.

JURASSIC OR CRETACEOUS SYSTEM.

Morrison formation.—The gray clay of the Morrison formation overlies the Sundance formation, and is exposed at many places from the Haystack Range eastward to the fault south of Glenrock and in the ridges south of Douglas.

The thickness of the formation averages about 150 feet, and its upper and lower limits are clearly defined. White and pale greenish-gray clay or massive shale predominates, but some portions weather pink, buff, or maroon. Thin beds of sandstone and limy concretions are included in the formation. Bones of characteristic dinosaurs occur in some places, notably in Como Bluff and the Freezeout Hills, a short distance southwest of the area treated in this report.

CRETACEOUS AND TERTIARY SYSTEMS.

Cloverly (?) sandstone.—The prominent sandstone series overlying the Morrison is for the present known as the Cloverly (?) sandstone, but it may here include beds having a greater range of age than in the type locality. It constitutes a large part of the Haystack Range, and its outcrop extends as a hogback ridge along the south side of the Deer Creek valley to the fault south of Glenrock. It appears again in the numerous ridges south of Douglas and also in a small area south of Inez. The thickness of the Cloverly (?) beds ranges from 90 to 140 feet. The rock is mainly gray massive sandstone in two members, separated by 20 to 40 feet of clay or shale of buff to maroon color similar to the Fuson formation of the Black Hills. The basal portion is conglomeratic at most places. The upper sandstone is thin bedded and rusty in color. South of Douglas there are three sandstone members.

Benton shale.—In the Benton shale begin the thick deposits of black shale, which constitute a large part of the Upper Cretaceous section. The formation occupies an area of considerable extent in the syncline of Muddy Creek and in the valley of Little Medicine Bow River. Its outcrop also extends along part of the valley of Bates Creek, the north slope of the Casper Range, and the foot of the mountain south of Glenrock. The Benton shale is about 1,500 feet thick. About 225 feet above its base it includes the Mowry shale member of light-gray hard shale containing large numbers of fish scales. This member is about 175 feet thick and is succeeded by dark shale containing a 100-foot sandstone member about 300 feet below its top.

Niobrara shale.—The dark shales at the top of the Benton give place within a short distance to the Niobrara shale, which crops out almost continuously along the north foot of the mountains from a point south of Casper to Boxelder Creek. It also crops out in the valleys of Bates Creek, Little Medicine Bow River, and Wagonhound Creek. The formation is about 250 feet thick, and the shales are in large part of light color, owing to the admixture of calcium carbonate. They weather to a pale-yellow tint, which is very characteristic. Some of the beds contain *Ostrea congesta*, mostly in small masses or thin layers.

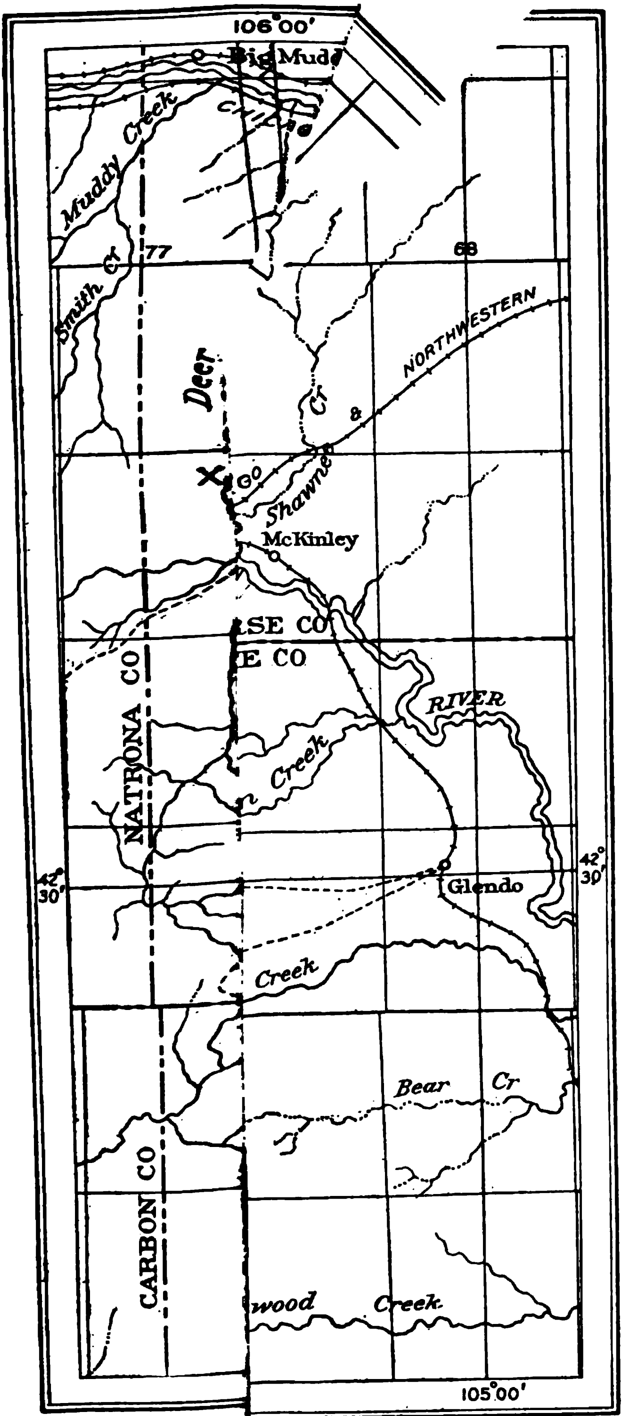
Later Cretaceous and early Tertiary formations.—Above the Niobrara shale in parts of this area are more than 9,100 feet of shales with interbedded sandstones and a few coal beds which represent the Steele shale, the Mesaverde, and higher Cretaceous formations; the Lance formation, classified as Tertiary (?); and the Fort Union formation, of Tertiary (Eocene) age.

White River formation.—The white clay and fine sand of the White River formation occur in many places on the northern slopes of the Laramie Mountains and adjoining ranges. Originally the formation covered all but the higher portions of the region, and much of it has been removed by erosion. Bodies of considerable size occur in the La Prele Valley about Beaver, and smaller outliers remain in the valleys south of the Deer Creek Range. A large area extends along the north slope of the mountains southwest of Douglas, and most of the La Bonte Valley as far south as Spring Hill is in White River beds. In many places these deposits contain bones which indicate that they are of Oligocene age.

MINERAL DEPOSITS IN THE NORTH LARAMIE MOUNTAINS.

DEVELOPMENT.

Evidences of prospecting, assigned by local tradition to the period immediately following the discovery of gold in the Cherry Creek and Pikes Peak districts in Colorado, are to be noted from place to place within the area of crystalline rocks lying northwest of Laramie Peak. Stories of gold having been won by individuals and of lost mines are current, but no printed records are known to justify the belief that there has ever been any production worthy of mention. A discovery of gold in the vicinity of War Bonnet Peak, 15 or 20 years ago, caused a short-lived interest in the country at the head of La Prele and La Bonte creeks. Though a promising vein was discovered the ore proved to be a mere pocket, and systematic work was soon abandoned. Since about 1875 more or less prospecting has been going on in one place or another, during more recent years mainly in the search for copper ores.



LIST OF PROSPECTS

1 TRAIL CREEK
2 SNOWBIRD
3 SAUL'S CAMP
4 KREISLEY PROSPECTS
5 THREE CRIPPLES
6 MAGGIE MURPHY
7 HOOSIER BOY
8 MAMMOTH
9 PYRAMID
10 LA BONTE CLAIMS
11 MAGNETITE LOCALITY
12 COPPER KING
13 ORIOLE
14 BRENNING
15 CHROMITE
16 SWEDE BOY
17 MORMON CANYON (copper and asbestos)
18 SMITH PROSPECT
19 MEWIS PROSPECT
20 HAZENVILLE

X4
Prospect
(Number refers to list)

OSPECTS.

The results of work thus far have been disappointing, and after having visited nearly all the principal prospects the writer concludes that there is little or no chance that really extensive copper deposits will ever be developed. It may be that some small deposits will be mined, but even for these the outlook is not very encouraging.

Several occurrences of magnetite were noted, but though some of the material is rich in iron, there are no indications that large deposits exist.

Chromite occurs in western Converse County but is remote from railroad transportation, and the writer's observations indicate that the deposit is not of sufficient size to warrant the undertaking of mining operations.

Deposits of asbestos in Natrona County, south of Casper, were not studied in connection with the present report, as they have been described by Diller.[1] There has been some prospecting for this mineral in western Converse County, but there has been no production, and if workable deposits exist, it is not likely that they will have any value, unless efforts to place the more fully developed deposits, referred to above, on a profitable industrial basis are successful.

Although no mining districts have been organized, the country immediately tributary to Esterbrook post office has been called the Spring Hill or preferably the North Laramie Peak district; the head-water region of La Prele and La Bonte creeks has been called the War Bonnet district, and part of the country drained by Deer Creek the Deer Creek district. Mining claims in Converse County must be registered in the United States land office at Douglas and those in Albany County at Laramie.

The accompanying sketch map (Pl. V) shows the approximate locations of the mining prospects that are mentioned in the following pages.

NORTH LARAMIE PEAK DISTRICT.

LOCATION AND GEOLOGY.

Esterbrook post office, near the center of the North Laramie Peak district, is about 25 miles south of Douglas and 20 miles west and somewhat south of Glendo. The district may be regarded as comprising an area measuring about 15 miles from east to west and 12 miles from north to south, the northern half lying in Converse County and the southern half in the northeast corner of Albany County.

Prospecting for mineral deposits has been carried on principally in the eastern part of the district. Here the gravel and sand deposits of

[1] Diller, J. S., The types, modes of occurrence, and important deposits of asbestos in the United States: U. S. Geol. Survey Bull. 470, pp. 505-524, 1911.

the White River formation overlap the crystalline rocks both from the north and from the east, but in such a manner as to leave an irregular area of the crystalline rocks extending about 7 miles northward from Esterbrook. The general distribution of the crystalline and younger rocks is shown on figure 3.

The crystalline rocks comprise dark schists that are usually rich in hornblende and locally contain mica, dikes of basic rock intrusive in these schists, and granites that are regarded as older than most of the basic dikes. The platy structure in the schists, most of the granite boundaries, and the dikes strike southwest. Beginning about 1½ miles north of Esterbrook, where the wagon road crosses Little Horseshoe Creek, there is a belt of country about 2 miles wide in which the hornblende schists and accompanying basic dikes are not interrupted by any large bodies of granite, but on the northwest and the southeast this belt is flanked by areas showing alternating bands of granite and schist. Observations in the main area indicate that the schists have been derived in large part from a complex set of volcanic lavas and tuffs interbedded with some ordinary sediments. That the sediments included limy layers is shown by the presence of epidote and garnet in some of the schists. Though some of the dikes are not laminated, the minerals of others have yielded to pressure, so that it is not everywhere possible to distinguish the dike rocks from those which they invade. Outside of the main schist area the same difficulty is encountered, and though in the wider bands the schists are regarded as forming a matrix for the granite, in the narrower ones the dark rock is probably as a rule intrusive with respect to the granite.

GENERAL CHARACTER AND OCCURRENCE OF THE MINERAL DEPOSITS.

There has been more prospecting in the older schists than in those that are supposed to be metamorphosed dikes, but the latter show some mineralization in several localities. Exploration work has consisted mainly in the prospecting of rock masses that are more or less thoroughly charged with one or both of the iron sulphides pyrite and pyrrhotite, but in several places there are veinlike bodies of quartz that carry metallic sulphides. Perhaps as a rule pyrite and pyrrhotite are accompanied by some chalcopyrite, though usually the proportion of this copper mineral is small and in places it is not visibly present in the sulphide-bearing material. Pyrrhotite deposits resembling those found near Esterbrook occur in the Hartville district, in eastern Wyoming, and have been prospected for copper. Galena occurs with pyrite and chalcopyrite in the Esterbrook lode but was not noted elsewhere.

As a rule the lodes and country rocks are very tight and dense, that they are not readily penetrated by surface waters. In con-

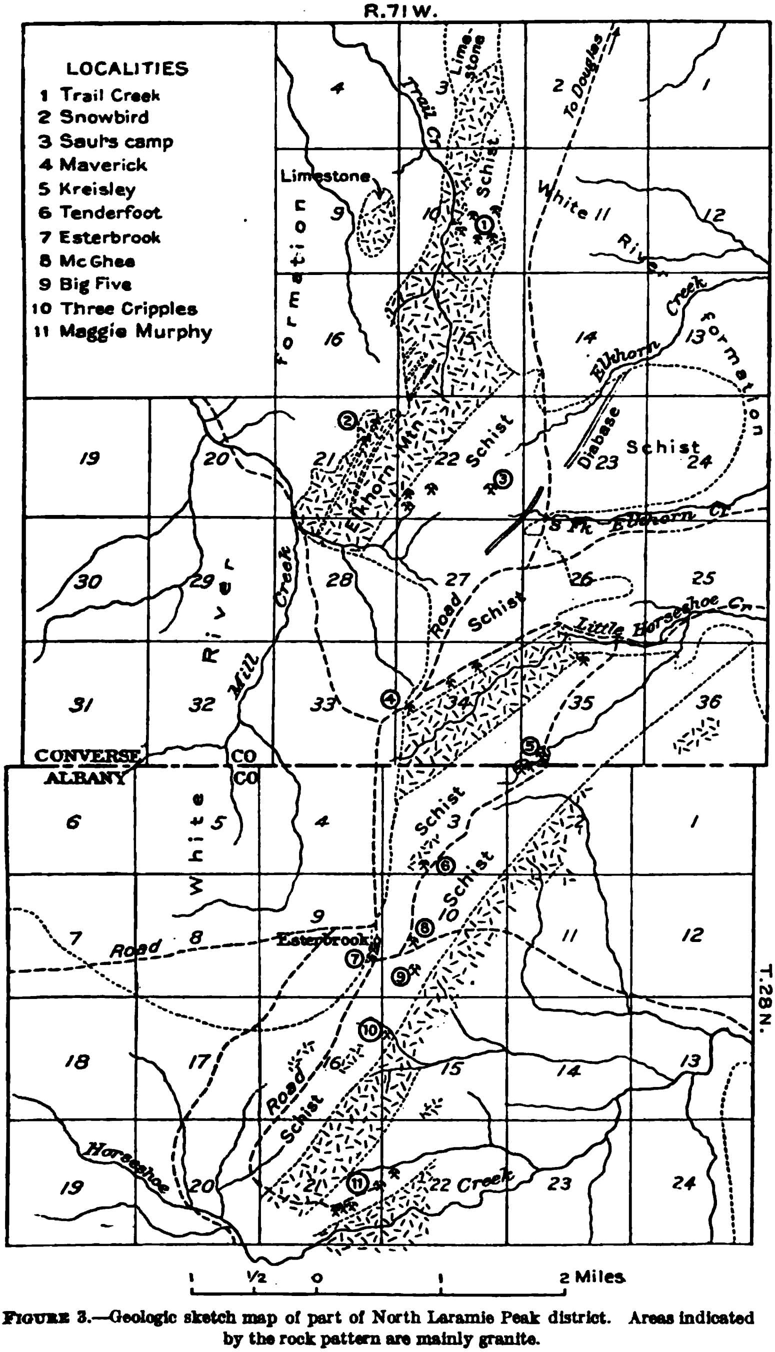


FIGURE 3.—Geologic sketch map of part of North Laramie Peak district. Areas indicated by the rock pattern are mainly granite.

sequence the lodes are not deeply weathered, sulphides may appear within a few feet of the surface, and there has been very little sulphide enrichment. However, in a few places pockets of chalcocite have been found near the surface, and green or blue copper carbonates are present here and there in the limonite caps. Usually water stands at depths less than 60 feet.

The sulphide deposits are tabular bodies or thin lenses that have been formed probably through partial replacement of preexisting rock. They occur in overlapping arrangement in more or less definite belts. The separate bodies and the belts as a whole strike southwest, parallel with the structure of the country rocks. So far as noted the dips are nearly vertical or to the northwest at rather steep angles. A line from Horseshoe Creek canyon northward through Esterbrook crosses the schist and granite belts diagonally and in a distance of about 9 miles intersects eight or nine fairly distinct sulphide belts. Nearly all the prospecting has been done within a north-south zone nowhere much more than 2 miles wide. Because only parts of this zone were traversed and outlying localities were not visited, no general statement can be made concerning the full extent of mineralization along the strike of the several sulphide belts. However, men familiar with the region report that mineralization like that in the vicinity of Esterbrook occurs from place to place as far southwest as Eagle Peak, which is a prominent landmark situated west of Laramie Peak.

MAGGIE MURPHY BELT.

The mining claims known as the Maggie Murphy group are about 3 miles south of Esterbrook, on the north side of Horseshoe Creek. The gorge of this stream is here about 700 feet deep, and its course is a little north of east. About half a mile farther south is a line of high rugged hills composed of coarse reddish granite, and the same rock forms the steep but flaring walls of the gorge. North of the canyon rim is a terrace or bench where hornblende schists are interlayered with minor masses of granite, and less than half a mile to the north rises another line of prominent granite hills. Here as elsewhere in the district the general trend of structural lines is southwest, but the strikes are somewhat more easterly than in the country to the north.

About 1900 the attention of prospectors was attracted to this locality by several outcrops of rusty schist showing small amounts of green copper minerals. This material was rightly judged to be the oxidized capping of sulphide deposits, and subsequent exploration by means of a shaft revealed the presence of a heavy body of the magnetic iron sulphide pyrrhotite. The iron cap is said to have been

very shallow. The shaft was sunk to a depth of 107 feet, and several minor openings were made, showing that sulphide mineralization extends at least half a mile toward the southwest and for some distance northeast of the main workings.

In one of the southwestern openings a layer of graphite-pyrrhotite schist from 1 to 2 feet thick was found to carry some chalcopyrite. Several hundred pounds of rock taken from the shallow shaft may have contained 3 or 4 per cent of copper, but samples that show no visible chalcopyrite were found by laboratory tests to contain no copper. In another opening in the southwestern section massive pyrrhotite was found.

The material from the deep shaft is principally schist composed of hornblende or hornblende and quartz mixed with pyrrhotite. Some of the rock is composed mainly of pyrrhotite, the hornblende and quartz being distributed as isolated grains or small bunches. Most of the material on the dump contains no visible chalcopyrite. It is not difficult to find specimens that contain chalcopyrite in considerable quantity, but apparently it occurs only in rock that contains also a greenish feldspar (oligoclase), which is usually rather coarsely intercrystallized with quartz. This feldspar-quartz material is present in relatively small amounts, and its relation to the mass of sulphide is not clear. So far as seen it does not occur in clean-walled veins or dikes, still its general appearance suggests that it has been injected into the pyrrhotite-bearing rock. Bunches of pyrrhotite that are found in it may be inclusions broken from the matrix. The chalcopyrite is mainly contemporaneous in crystallization with the feldspar and quartz, but it also occurs with the iron carbonate siderite in minute veinlets cutting these minerals. Rusty outcrops 300 to 400 feet southwest of the shaft and pits in limonitic material northeast of the shaft indicate that there is here a body of the pyrrhotitic rock from 10 to perhaps 40 feet wide and several hundred feet long, but the material seen on the dump does not suggest the presence of any valuable body of copper minerals. A possibility worthy of some consideration, however, is that there may be interlayered shoots of copper ore in the pyrrhotitic rock. Indications of such shoots might be sought by means of surface trenches or by shallow tunnels driven across the lode. Deep exploration should not be undertaken unless encouraging results are first obtained by prospecting near the surface.

At the time this property was being prospected several buildings were erected which are still in good condition. The wagon road from Esterbrook, though now in rather poor shape, could be repaired with slight expense.

THREE CRIPPLES AND TENDERFOOT BELTS.

Just northwest of the schists of the Maggie Murphy locality is a belt about 2,000 feet wide occupied mainly by granite but showing also thin layers of dark schist which are regarded as metamorphosed diabase dikes. About a mile southeast of Esterbrook prospecting in schists belonging to this belt has revealed the presence of disseminated pyrite, but nothing that can be regarded as of practical importance has been discovered.

Beyond the granite belt there is a belt occupied mainly by hornblende schists but containing some intercalated bodies of pink granite and locally dikes of white pegmatite. Southwest and west of Esterbrook the full width of this belt is not seen, because here the crystalline rocks are hidden by White River deposits, but to the northeast it is nearly a mile wide. Within this belt near Esterbrook and for 3 miles to the northeast there are many shallow pits showing ferruginous material evidently derived from sulphide-bearing rock, and in several places pyrrhotite or pyrite bodies have been found. From a rather cursory study it seems that the whole belt may comprise two or perhaps three fairly distinct minor belts of sulphide deposits. With respect to the possible occurrence of copper deposits, the results of prospecting thus far are not regarded as encouraging.

About half a mile south of Esterbrook post office is the Three Cripples shaft, said to have been opened to a depth of 96 feet in 1905. The immediate country rock is black schist, but a short distance southeast of the shaft there is a contact between this rock and coarse pink granite. The dump shows a large amount of massive pyrrhotite rock in every way like that from the Maggie Murphy shaft. A sample consisting of 25 chips taken from different parts of the dump was analyzed in the chemical laboratory of the Geological Survey by R. C. Wells with the following result:

Analysis of Three Cripples pyrrhotite rock.

Insoluble	28.38
Iron	41.80
Copper	.23
Cobalt	Trace.

Nickel, platinum, gold, and silver were not detectable in this material.

Here, as at the Maggie Murphy, portions of the rock that carry visible chalcopyrite also contain feldspar-quartz aggregates or bunches of quartz. The proportion of such material in the rock that has been mined is small. The surface improvements comprise a shaft house and a cabin, both in good repair. Part of the machinery has been taken away.

Though there are practically no outcrops along the Three Cripples lode it is possibly represented by iron caps disclosed in pits about 1,000 feet southwest and 1,800 feet northeast of the shaft.

Somewhat to the northwest of the supposed northeastward extension of the Three Cripples lode iron cap has been found in several pits whose positions suggest the presence of two other lines of sulphide bodies, making three in all within a band 600 feet wide bounded on the southeast by granite. Sulphides have been reached only at a shaft known as the Big Five, which is on the northwesternmost of these lodes, about 2,500 feet north-northeast of the Three Cripples shaft. This opening is probably about 50 feet deep. The material on the dump is mainly pyrrhotite rock, and here again chalcopyrite is seen only where bunches of quartz or feldspar and quartz are present.

About 1,200 feet north of the Big Five is an opening known as the McGhee shaft. Here there are gray schists more or less thoroughly charged with pyrite, but nothing of practical significance was found. This deposit may be regarded as belonging to the Three Cripples sulphide belt. Probably this belt extends for some distance northeast from the Big Five shaft, but it was not traced in this direction by the writer.

If the Big Five location is taken as being near the axis of the Three Cripples belt, the medial line of the Tenderfoot belt (p. 65) lies 1,800 or 2,000 feet to the northwest. Prospecting at several points along this belt has extended from Esterbrook northeastward for about 3 miles.

At Esterbrook a tabular body of quartz and calcite carrying lead carbonate at the outcrop and galena below the surface has been prospected, mainly by the Boston-Wyoming Copper Co. Though but poorly exposed the country rock appears to be mainly hornblende schist, but the principal outcrops are white pegmatite dikes from a few feet to 50 feet wide. Some of these dikes are greatly curved, as if they had been injected into contorted schists, but no direct evidence of structure of this sort was seen.

Along the outcrop siliceous lead carbonate occurs as a nearly vertical layer from a few inches to perhaps 3 feet thick, flanked on the west by 1 to 3 feet of finely crystalline calcite. The strike of these layers, as seen in a trench 100 feet long, ranges from N. 30° E. near the south end to N. 15° E. toward the north. From several workings it is seen that the main outcrop is not less than 500 feet long. Toward the south the lode appears to fork, and though it is not continuously exposed, what may be the easterly spur is seen in a pit situated nearly 400 feet from the main shaft on the east side of the wagon road.

There are three shafts on the strike of the lode. The Newell shaft, to the north, between two outcrops of white pegmatite, appears not

to have disclosed either lead minerals or the calcite layer which has been mentioned. About 270 feet south of the Newell shaft is an opening 60 feet deep, now used as a well, from which some ore has been taken, and 270 feet farther south is the principal shaft, 350 feet deep. On the main level at 335 feet drifts are said to have been opened in 1909 and 1910, 300 feet toward the south and 100 feet toward the north.

The material on the main dump consists principally of black schist but includes some rock having a massive appearance, which has been found by examination with the microscope to be a somewhat altered diabase. With the schist and diabase there are considerable amounts of calcite rock, and so far as seen the ore minerals occur only in association with this material. Presumably the relation is generally like that at the surface, where the ore layer lies parallel with the calcite layer. Chunks of the calcite rock contain thin layers of dense quartz and other layers containing disseminated grains and bunches of galena and of chalcopyrite, and at least locally such material appears to have formed the immediate wall of the galena streak. It is thought that the quartz and the sulphide minerals were deposited in partial replacement of the calcite. The course of the main lode corresponds with the strike of the hornblende schists in the neighborhood, but if the vein forks, as is suggested above, one of the spurs probably breaks across the country structure.

Though nothing that can be regarded as ore remains on the dump, it is reported that shoots of nearly solid galena 6 feet wide were found in the mine workings and that shipments of such ore were made. As already noted, chalcopyrite occurs in some of the lode stuff, but it is not present in any considerable amount. Persons directly concerned in this development were not interviewed, so that no statement can be made concerning the amount of ore that has been taken from the mine. However, about 17 tons of carbonate ore shipped prior to 1904 is reported to have given the following returns: [1]

Assay of Esterbrook lead ore.

Silver	ounces per ton	1.4
Gold	do	.035
Lead	per cent	34.65
Iron	do	7.00
Silica	do	34.00

The underground workings of this property were not accessible in 1914. Although, as shown above, the surface ore is very siliceous, it is sufficiently evident from the character of the material on the dump that oxidation does not extend to any great depth, and if shoots of galena are found this mineral could be readily and cheaply freed from

[1] Beeler, H. C., The North Laramie Peak copper district, p. 10, Cheyenne, 1904.

associated quartz or calcite. The boilers and hoist are well housed and appear to be in good condition.

Somewhat more than half a mile northeast of Esterbrook mining explorations were made about 1900 on claims known as the Tenderfoot group. In this section the belt of sulphide deposits is not less than 2,000 feet wide, as shown by pits and shafts in bodies of iron capping. Near the west side of the belt, about 200 feet west of a line of iron-stained croppings, a shaft 150 feet deep was put down, but a crosscut directed toward the southeast was abandoned before reaching the lode. The lode is probably made up of pyrrhotite.

Beyond the Tenderfoot location several openings were noted in iron cap, and doubtless there are others, which were not seen, to prove the continuance of this sulphide belt toward the northeast. About a mile from the Tenderfoot shaft is the Kreisley group of claims, where prospecting during the last two or three years has disclosed large bodies of pyrrhotite. Here, as usual, there are several parallel lodes. One of them is readily traceable for more than 600 feet and in places is certainly not less than 50 feet wide. Material from two shafts shows pyrrhotite mixed with hornblende and quartz, and similar rock essentially unoxidized crops out in the bed of a small creek.

When this property was visited in August, 1914, the owners were unwatering a shaft about 100 feet southeast of the pyrrhotite lode mentioned above. Here neither pyrrhotite nor pyrite had been encountered at a depth of 60 feet, the material from the shaft being yellow to red oxidized schist in which minor bunches and stringers of secondary copper minerals were found.

The northwestern edge of the schist zone that comprises the Three Cripples and Tenderfoot sulphide belts lies about 2,500 feet from the Kreisley workings. Near this edge and north of the Kreisley camp another line of pits in red and yellow jaspery iron cap was noted but not examined in detail.

MAVERICK PROSPECTS.

Northwest of the belt of schists that passes through Esterbrook there is a belt of granite about 2,000 feet wide, and beyond this lies what has been called on page 58 the main body of schists. The granite belt contains some schist, but the main schist area is sharply defined along a southwest-northeast contact with granite. Close to and parallel with this boundary there is a line of prospects about 4,000 feet long. The Maverick location is at the southwest end of this line just north of Little Horseshoe Creek. The type of mineralization here is different from that along the sulphide belts that have been described. Irregular veins of quartz from 3 to 10 feet wide follow a

general line parallel with the strike of the schists and trend from N. 45° W. to N. 55° W. There are several narrow dikes of pegmatite, and in one place a quartz vein grades into rock of this sort. On the Maverick claim there are two vertical quartz veins, both iron stained and rather vuggy, as seen at the surface. One of these veins 3 to 4 feet wide crops out for a distance of 60 feet. The other vein, 6 feet wide, lying to the southeast, has been opened by a 50-foot shaft. The rock on the dump is quartz containing irregular bunches of pyrite. No copper minerals were seen.

About 2,000 feet northeast of the Maverick shaft is a quartz vein 2 to 10 feet wide that forms a continuation of a pegmatite dike. There is no indication that the pegmatite carries pyrite, but the quartz is very ferruginous throughout the 300 feet of exposure. Along the strike of this vein 500 and 800 feet to the northeast there are pits in light-colored schists that seem to have contained pyrite.

SAUL'S CAMP.

The Maverick line of prospects noted in the preceding paragraphs lies along the southeast side of a belt of hornblende rocks nearly 2 miles wide, which is not broken by any large bodies of granite. In the central part of this belt, in the SE. ¼ sec. 22, T. 29 N., R. 72 W. (see fig. 3), is Saul's camp, where a group of 29 mining claims was located several years ago and surveyed for patent in 1914. Many prospect shafts have been opened, and in several of them copper minerals were found. The country rocks are mainly hornblende schists that the writer believes to be metamorphosed volcanic rocks. Locally there are layers that contain epidote or garnet, suggesting that the rocks from which the schists were derived contained thin beds of limestone. Several dikes of black basic rock like diabase cut the schists, and toward the northwest side of the schist belt there are several minor intrusions of granite. The layering in the schists strikes in general about N. 45° E., and the intrusive dikes trend in the same direction. The principal workings are on the Tarsus No. 1 claim, on the southeast slope of a prominent hill and the shaft is formed by ledges of black diabasic hornblendite.

A rather inconspicuous outcrop of gossan contained copper carbonate, and chalcocite was found in the first shaft only a few feet below the surface. This shaft was carried to a depth of 60 feet, and as the lower part showed nothing of particular promise, at a depth of 30 feet a northeast drift was started to follow a streak containing copper minerals. About 25 feet from the shaft a mass of chalcocite ore was cut. This ore proved to be a saddle-like body forming a crest or cap over a chimney of white clay. A raise was opened to the surface, and the clay was found to continue 15 feet below the

drift, or to a point about 45 feet from the surface. At that depth the first water was encountered, and near the water level small amounts of metallic copper were noted. The shaft was carried down to 98 feet, and at 85 feet a layer or lens of chalcopyrite-bearing rock 12 inches thick was found 12 feet southeast of the shaft. The schist lying between this lens and the shaft is reported to carry about 2 per cent of copper.[1]

The material on the dump consists mainly of hornblende schist but includes a large amount of pyritic rock, portions of which carry visible chalcopyrite. No pyrrhotite was noted, but nearly solid magnetite occurs as a layer about 8 inches thick. Samples of the richer ore have shown as much as 30 per cent of copper and from 6 to 8 ounces of silver and 0.03 ounce of gold to the ton. About 100 tons of ore said to carry about 9 per cent of copper was taken out during the development work, and most of this ore remains in the bins.

About 200 feet northeast of the main shaft limonite carrying small amounts of chalcocite and malachite has been opened by a 20-foot shaft. Outcrops near by show iron-stained rock containing small crystals of epidote.

About 400 feet east of the main shaft an opening 35 feet deep shows weathered hornblende schist that is strongly limonitic. In this vicinity, mainly toward the southeast, the compass needle is greatly disturbed, and the inference may be drawn that within an area perhaps 300 feet wide there are rocks carrying considerable amounts of pyrrhotite or of magnetite. Mr. H. C. Saul stated to the writer that a zone of magnetic disturbance can be traced for 1,000 feet or more toward the southeast.

At the 35-foot shaft two diamond-drill holes were bored. One, nearly vertical, is 256 feet deep; the other, inclined about 42° NW., is 250 feet on the incline. The cores from these holes show greenish schist with here and there a little pyrite or pyrrhotite and some minor showings of chalcopyrite. The amount of pyrrhotite contained in the rocks penetrated can not be regarded as sufficient to account for the observed deflection of the compass needle in this locality, and it is suggested that a body of magnetic iron sulphide may be present southeast of the shaft.

The equipment of the property includes a steam boiler, a hoist, and a diamond-drill outfit. There is an adequate shaft house and several other buildings.

From the foregoing notes it will be understood that the prospecting at and near the Tarsus shaft is not extensive. The work has been done in an intelligent way, and the results at the main shaft may be

[1] Saul, H. C., Mining operations in the North Laramie Peak mining district, Wyo.: Min. and Eng. World, vol. 40, p. 738, 1914.

regarded as somewhat encouraging. It appears to the writer that if additional explorations are made, one of the first steps should be to follow the chalcopyrite-bearing layers found in the shaft along their strike. Although results of prospecting the deposits of pyrrhotite that occur to the south have been discouraging, this can not be urged as an adequate reason against undertaking explorations in the zone of magnetic disturbance at Saul's camp.

About 2,500 feet from the Tarsus shaft, in a direction slightly north of west, a small body of chalcocite ore was found practically at the surface. Examination of the pit, which is situated on a high ridge, indicates that the ore occurred as a layer striking northeast, but the work done is insufficient to give any clear impression of the relations.

In a valley northwest of the locality just mentioned some prospecting has been done along a belt of pyritic hornblende-mica schist. Copper minerals are present, but nothing was seen that the writer would regard as warranting further development.

Approximately 3,000 feet northwest of the Tarsus shaft is the northeastward-striking boundary of the main schist area against granites that form a high ridge known as Elkhorn Mountain. (See fig. 3, p. 59.) In several places along this boundary for a distance of nearly 5,000 feet there are outcrops of dense white or greenish quartz. Although locally hidden and perhaps absent in places, this quartz appears to be a rather definite layer and where exposed is from 20 to 130 feet thick. It has not been prospected except at a point due west of the Tarsus shaft, where material from an 8-foot pit carries small amounts of pyrite and chalcopyrite.

SNOWBIRD GROUP.

The five patented mining claims known as the Snowbird group are about 1 mile from Saul's camp (see figs. 3 and 4), on the northwest side of Elkhorn Mountain. Granite is the principal country rock in this neighborhood, but there are two narrow bands of greenish schist that is regarded as sheared diabase, and just to the west is an extensive area underlain by partly consolidated sands and gravels belonging to the White River formation. The claims, which extend from northeast to southwest for a distance of nearly 7,500 feet, were evidently located with the object of covering a body of schist from 60 to 150 feet wide which is flanked by granite on both sides. Aside from shallow pits which show nothing of interest, the development work consists of two shafts—one, said to be 40 feet deep, and the other, 80 feet deep, about 2,500 and 3,800 feet, respectively, from the northeast end of the property. Northeast of the 40-foot shaft there are no bedrock outcrops, but at this place the dark schist appears, and a short distance to the southwest there are exposures of coarse

granite or pegmatite about midway between the sides of the schist belt. This pegmatite continues, apparently as a dike from a few feet to 15 feet in width, for several hundred feet, but at the 80-foot shaft its place is occupied by a strong vein of quartz. The granitic rock and the quartz body probably grade one into the other, but the exposures are not adequate to prove it. Material from the northeasterly shaft includes pegmatite and vein quartz and considerable

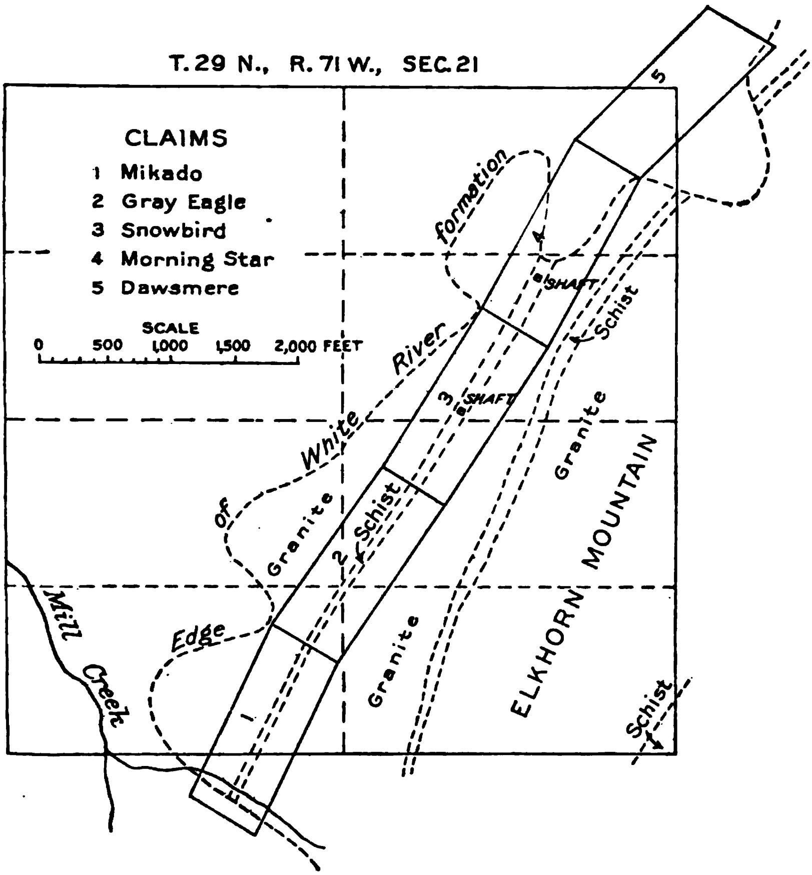


FIGURE 4.—Sketch map of Snowbird group, showing schist bands in granite.

iron-stained dirt. Specular hematite was noted, and there are minor showings of copper minerals. As seen at the surface near the southeasterly or main shaft the quartz vein is not less than 10 feet wide. The rock on the dump includes schist and quartz containing chalcopyrite, and small amounts of chalcocite and other secondary copper minerals were noted. From a study of the surface it is thought that the quartz vein may have a total length of 500 to 600 feet.

TRAIL CREEK GROUP.

About 2 miles north of Saul's camp is a group of mineral locations known as the Trail Creek claims. These claims cover a group of schist hills lying between two sharp canyons near the head of Trail Creek, a tributary of La Bonte Creek. In this vicinity (see figs. 3 and 5) the crystalline rocks appear in a band hardly more than half a mile wide with White River beds on both sides. The Elkhorn Mountain mass of granite extends along the southeast side of the schists of the Trail Creek group of claims, and the same rock cuts

T. 29 N., R. 71 W., SEC. 10

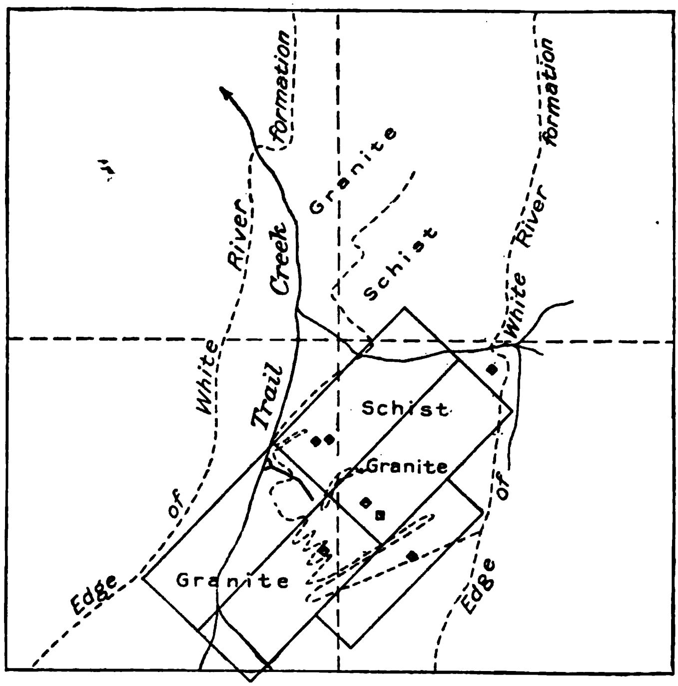


FIGURE 5.—Sketch map of Trail Creek group, showing local geology.

out these schists along their strike toward the southwest and flanks them again upon the northwest. Thus the general relations show that the schists are intruded by the granite, and this is shown also by narrow shoots of the igneous rock that penetrate the schists along the southwest side of the area. The invaded rocks are mainly hornblende schists striking southwest, but there are several large and many small irregular masses of iron-stained jasper. In one place a narrow jaspery vein carries considerable epidote. Evidences of sulphide mineralization are seen at many points where openings have been made in weathered iron caps.

The principal workings are a 75-foot shaft and a tunnel nearly 500 feet long near the west side of the schist area. The shaft is in coarse granite a few feet away from its contact with the schists. Here the rock is fractured, and in the breaks malachite and chalcocite occur in noteworthy but not large amounts. The level of the tunnel is 8 or 10 feet above the creek bed and more than 100 feet below the collar of the shaft. For the first 30 feet it is in granite, beyond which almost completely weathered hornblende schists are exposed. The presence of unoxidized remnants in several places and the generally ferruginous nature of the weathered material show that the rock was all very pyritic. About 75 feet from the tunnel portal a winze was sunk 25 feet on a body of ferruginous quartz which is said to have contained small amounts of copper minerals. Massive quartz from the lower part of the winze contains irregular bunches of pyrite, but no chalcopyrite was found. In August, 1914, after an unusually dry season, water was standing 10 feet below the tunnel floor. About 50 feet beyond the winze water was trickling down the sides of the tunnel, and here a slight deposition of copper salts was noted. No other copper signs were observed in the tunnel, and nothing regarded as encouraging was seen on the dump.

HOOSIER BOY GROUP.

About 1904 some prospecting was done on two groups of mining claims, known as the Hoosier Boy and Kentucky Belle properties, situated about 10 miles southwest of Esterbrook and 8 miles northwest of Laramie Peak. (See Pl. V.) The principal country rock is granite, but there are narrow dikes of schistose diabase which trend about N. 70° E., and it is along one of thesee dikes that the six Hoosier Boy claims and the two Kentucky Belle claims were located, their aggregate length being 12,000 feet. The Hoosier Boy claims lie mainly in a high grassy valley at the head of a tributary of La Bonte Creek, and the Kentucky Belle claims to the southwest, beyond a divide between La Bonte and Horseshoe Creek waters. Systematic prospecting, by means of shafts, was done at two points about a mile apart. In both places there are quartz veins that have the same strike as the dike of schistose rock in which they occur. These veins pinch and swell but are continuous or at least recurrent for distances of several hundred feet. At a point about 400 feet northeast of the Hoosier Boy shaft vein quartz grades into a mixture of quartz and feldspar. Some of the material from the shaft, which is said to be about 80 feet deep, contains small amounts of chalcopyrite.

The Kentucky Belle shaft is about 40 feet deep. The somewhat irregular quartz vein, which has a maximum width of perhaps 2 feet, carries considerable chalcopyrite and some chalcocite, the latter evidently of secondary origin.

WAR BONNET DISTRICT.

LOCATION AND GEOLOGY.

The War Bonnet district, bearing the name of a prominent peak situated near the southern edge of Converse County, may be regarded as comprising the country drained on the north by the headwater tributaries of La Prele Creek and the west fork of La Bonte Creek and on the south by some of the sources of Sheep Creek and Little Medicine Bow River. The country rock is mainly granite, but, as elsewhere throughout the North Laramie Mountains, this rock is cut by dikes of diabase, and the invading rocks have been rather generally converted into schist. The common trend of these dikes is about N. 50° E. In a few places schists were seen which may belong to a series of rocks that is older than the granite.

PROSPECTS NORTH OF FORTYMILE RANCH.

The Fortymile ranch, a station on the now abandoned stage road from Rock Creek north to Fort Fetterman, is situated near the head of West Fork of La Bonte Creek, in sec. 3, T. 27 N., R. 74 W. sixth principal meridian. From this place the stream flows nearly north through a rather open valley for about 3 miles and then turning east soon enters a deep and narrow gorge called La Bonte Canyon. Near the head of the canyon and also toward the west are dikes of diabase along and near which there has been considerable prospecting for copper. The most extensive work was done by incorporated companies known as the Pyramid Copper Co., the La Bonté Mining Co., and the Mammoth Mining & Milling Co. (See Pl. V.)

The property of the Pyramid Co. appears to have been taken over by the La Bonté Co., which held adjacent ground and which is said to have secured patents to five mining claims. Two lodes or veins were explored. One of these, the Pyramid vein, takes its name from a column of quartz-seamed granite about 25 feet high known as The Pyramid. The vein crops out at the base of this column and as exposed for a distance of about 75 feet has a width of about 20 feet. The vein strikes about N. 53° E. and is nearly vertical. Toward the southwest it is covered by gravel deposits in the creek valley.

Near The Pyramid is a shaft 30 feet deep, on the dump of which lies several tons of rock estimated to carry 5 per cent of copper. About 70 feet northeast of this shaft, just within the side valley, is the principal shaft, which was equipped with a steam hoist. The depth of this shaft may be as much as 100 feet. It was started at a point north of the vein, and as the rock on the dump is mainly granite the lode was probably not extensively explored. About 300 feet to the northeast a short tunnel has exposed a quartz body 3

feet wide which carries limonite at the outcrop and which is probably the continuation of the Pyramid vein. No attempt was made by the writer to trace this lode up the steep hill slope, but perhaps half a mile northeast of the Pyramid vein and approximately on its strike there are other exposures of quartz that carries copper minerals.

A short distance northwest of the Pyramid prospects hornblende schist crosses the side valley mentioned above and, trending northeast, appears as a dikelike body in a steep bluff on the east side of the stream about a mile above its mouth. Beyond the bluff the schist forms a prominent ridge, along which prospect pits have disclosed recurring lenses of quartz constituting an interrupted vein. Some of the quartz carries copper minerals. In order to prospect this ground a crosscut was opened from a point perhaps 250 feet below the crest of the schist ridge. The first granite and schist contact was cut 615 feet from the portal, and the far contact at 790 feet, showing the dike to be 175 feet wide. No considerable bodies of quartz were found in the crosscut, and a drift 200 feet to the northeast, 70 feet beyond the northwest wall, shows nothing but schist. Some of the rock on the dump contains disseminated pyrite, but copper minerals were not noted. This schist band was followed by the writer toward the northeast for more than a mile and is said to be traceable for several miles. It has been prospected at points approximately 1 and 2 miles northeast of The Pyramid.

About a mile southwest of The Pyramid a schist dike approximately on the strike of the one mentioned above has been prospected by a tunnel situated near the wagon road in the valley of the main creek.

The Mammoth vein is a body of dense quartz 50 feet or more in width which is traceable by scattered outcrops along a northeast course for a distance of perhaps 2,000 feet. This vein lies northwest of the tunnel referred to in the preceding paragraph. (See Pl. V.) Its outcrops are not generally rusty, but a single shaft has disclosed iron-stained material, showing that sulphide minerals are locally present.

About a mile northwest of the schist dike that traverses the La Bonté group there is another dike of the same sort of rock along which prospecting has been done at intervals for a distance of fully 2 miles. From place to place the schist forms the matrix of quartz bodies that conform with its northeast strike. Where work has been done pyrite is usually found, and in a few places copper minerals are present. It is said that 12 or 15 years ago rich gold ore was found in quartz occurring in this body of schist, on a claim situated a short distance beyond the La Bonte-Sheep Creek divide. This find led to nothing of value, though it is reported that the property was examined by men familiar with gold mining in South Dakota.

COPPER KING BELT.

About 30 miles southwest of Douglas, on a small tributary of La Prele Creek called Crazy Horse Creek, a quartz mass carrying chalcopyrite was systematically prospected at various times between 1902 and 1906 by the Douglas Mining & Milling Co. This company held five claims, including the Copper King, where most of the work was done, and other interests located and prospected claims in the neighborhood, mainly along the supposed extension of the Copper King lode.

The general country rock is granite, but the quartz vein occurs in one of the diabase dikes that are characteristic of the region. This and other dikes in the vicinity trend between N. 30° E. and N. 40° E. Some of them are readily traceable for a mile or more, and probably detailed study would show much greater continuity than could be made out from the writer's hurried observations. The Copper King claim lies within a northeast-southwest zone a few hundred feet wide along which vein fillings and other indications of mineral deposition were noted by the writer from place to place throughout a distance of 6 miles and which is said to have been followed and prospected for an additional distance of 10 miles toward the southwest.

About 2½ miles southwest of Crazy Horse Creek two schist bands separated by about 250 feet of granite were noted. The average width of these bands is perhaps 80 or 100 feet. From place to place along them quartz may be seen, and in several prospect pits quartz occurring in narrow seams carries magnetite. In one place magnetite and a little chalcopyrite were noted.

About 2 miles southwest of the Copper King claim there is a small deposit of nearly clean massive magnetite. The outcrop is hidden, but an area nearly 100 feet square is covered by bowlders of iron ore, some of which measure 2 by 3 by 3 feet. From the appearance of these bowlders they may be supposed to have come from a layer at least 2 feet thick. The small area covered by the float suggests that the deposit has the form of a lens. The magnetite is accompanied by a little quartz. Exposures near by show a band of green diabase schist about 80 feet wide, flanked by coarse granite. The magnetite layer probably occurs in the schist.

About three-fourths of a mile southwest of Crazy Horse Creek a 2-foot layer of magnetite schist was noted in a 10-foot prospect pit.

At several places both southwest and northeast of the Copper King claim prospectors have disclosed small bodies of quartz, but it occurs characteristically in stringers or in separated bunches rather than as continuous veins. There are signs of copper in different places outside of the Copper King claim, but nothing was seen upon which a prudent miner would spend time or money.

On the Copper King claim a shaft about 30 feet deep was opened in a large body of quartz carrying oxidized copper minerals in abundance at a depth of a few feet. A study of the surface shows that the quartz occurs as a series of lenticular bodies lying in schist near the southeast contact of a large horse of granite. Together these lenses form an interrupted vein that can be recognized for nearly 300 feet and may actually have a greater length. The discovery shaft is on a hill slope possibly 175 feet above the creek bottom. The development work consists of two tunnels, each said to be about 600 feet long.

The level of the upper tunnel is about 75 feet below the outcrop. Following the same general course as the dike, this tunnel cuts a narrow quartz vein about 140 feet from the portal. The vein gradually widens to 6 feet, then pinches and widens again to 12 feet, all in a distance of about 100 feet. Where the vein has its greatest width it contains a large proportion of chalcopyrite. This ore shoot is probably the same as the one opened at the discovery shaft. Near the portal of the tunnel a crosscut to the northwest reached the schist and granite contact, but no vein was found. A lot of perhaps 50 tons of ore was taken from the tunnel and from a winze 12 feet deep. Ore remaining on the dump is estimated to carry more than 15 per cent of copper, and it is reported that assays have showed as much as 0.35 ounce of gold to the ton. The tunnel was not accessible beyond the winze.

The portal of the lower tunnel is about 100 feet below that of the other and only a few feet above the creek. These workings were not accessible in 1914. The material on the dump consists almost entirely of dark-green schist but contains some vein matter consisting of quartz and siderite carrying a little feldspar. Vein stuff of this sort which carries small amounts of chalcopyrite is said to have come from the farther part of the tunnel.

Although the writer can form no satisfactory judgment concerning the possibilities of the deposit, he is of the opinion that the known ore shoot is worthy of being more fully prospected. A plan of the workings and a cross section through the shaft and the winze in the upper tunnel would aid in laying out future work, by indicating the position of the lower tunnel with reference to the probable position of the vein as projected downward from the winze in the upper tunnel. If the indicated position would carry it over the lower tunnel the vein should be sought by raising or by crosscutting to the northwest, whereas if the indicated position is to the southeast the vein should be sought by a crosscut in that direction.

ORIOLE BELT.

In the valley of upper La Prele Creek (see Pl. V), approximately 1 mile northwest of the Copper King line of prospects, is a parallel mineralized belt along which old workings were noted for a mile or more.

Here again diabase schist occurs in a granite country rock, and the general relations are similar to those along the Copper King belt. The only serious prospecting here was done about 10 years ago on the Oriole claim. On this claim a body of dense quartz from 20 to 30 feet wide crops out at intervals for nearly 1,000 feet along the edge of a steep bluff on the northwest side of La Prele Creek. The vein dips steeply toward the creek, and a few exposures are adequate to show that it has black or green schist on both sides. The development consists of two shallow shafts about 800 feet apart, both showing small amounts of copper minerals, and workings said to be 250 feet deep, about 300 feet southwest of the northeasterly opening. In the vertical shaft copper-bearing material is said to have been found only a few feet from the surface and to have continued to a depth of 175 feet, where the shaft passed out of the vein into the footwall. Next to this wall there was about 8 feet of rock that carried considerably more than the average amount of copper. No drifts were opened, but it is reported that the vein was crosscut at the 175-foot level and that another crosscut was started from a point 240 feet deep. In the upper crosscut, which is supposed to have reached the hanging wall of the vein, a flow of water was encountered which was too great for the capacity of the pump provided for sinking. The workings were thus flooded, and the operations have never been resumed.

Although it is apparent that the Oriole vein was not adequately prospected, the advisability of further exploration is open to question. Favorable to the property is the fact that several hundred tons of rock which may carry as much as 3 per cent of copper was taken out during the development work already done. On the other hand, the character of the vein stuff as seen in several exposures suggests that the vein does not carry copper minerals throughout. The only project that the writer would regard as at all promising would be the exploration of the footwall ore shoot that was cut by the shaft. This search might be made by means of a crosscut above the water level, followed by drifts along the footwall.

The Oriole property comprises several good houses. It is accessible by a good wagon road either from the north or from the south.

BRENNING COPPER PROSPECT.

The cross-mountain road by way of the upper valley of La Prele Creek passes the Oriole claim, crosses the divide at an elevation of about 8,000 feet, and by a choice of routes gives access to all adjacent parts of the high plains along the north side of Laramie Basin. About 4 miles west of the pass and just south of the Converse-Albany county line prospecting has been done on the Brenning claim. (See Pl. V.) The workings consist of two shafts in which large pieces of massive

chalcocite have been found. There are very few rock outcrops in the vicinity, but at the prospect hornblende schists are exposed. The chalcocite or copper glance is associated with bright-green, fairly well crystallized epidote. The epidote is present in large amounts, but the relation of the occurrence to the hornblende schist was not determined.

Similar epidote rock carrying rich copper ore is reported to occur at the Olin prospect, in the mountains at the head of Boxelder Creek, 4 or 5 miles north of the Brenning claim.

PERRY CLAIMS.

About 2 miles northwest of the Brenning prospect is a group of eight mining claims, here called the Perry group after one of the owners. These claims are arranged end to end and consequently they cover a strip of ground 12,000 feet long. The middle of the group is near the northeast corner of sec. 33, T. 29 N., R. 76 W. The country rock is mainly granite, but schistose dikes are present. The work done has disclosed several small veinlike bodies of quartz but no workable metalliferous deposits.

DEER CREEK DISTRICT.

LOCATION AND GEOLOGY.

Though the Deer Creek district is undefined it may be regarded as comprising the country between Boxelder Creek and the western boundary of Converse County. It is adjoined on the west by the Smith Creek asbestos district, in Natrona County.

The geology of the Deer Creek district appears from a cursory examination to be somewhat more complex than that of the War Bonnet district. Schists are present in greater abundance, and the granite intrusions are more irregular. Serpentine, which was not noted farther east, here occurs in many places.

SWEDE BOY VEIN.

The mining claim known as the Swede Boy is situated between Boxelder and Deer creeks about 16 miles south of Glenrock and somewhat less than 4 miles southwest of Boxelder post office. (See Pl. V.) Here a well-defined quartz vein in granite has been opened by an inclined shaft, and some copper ore is said to have been shipped. From the size of the dump it seems that the workings may aggregate 200 feet. Near the shaft the vein does not actually crop out, but from the alignment of several openings its course appears to be about N. 5° W. At the shaft mouth the vein is about 6 feet thick and its apparent dip is about 60° E. North of the main shaft and for 400

feet to the south the ground is covered by débris from near-by hills, but farther south float appears, and at minor shafts, 600 and 800 feet distant from the main workings, the vein is not less than 4 feet thick and shows the same easterly dip. Rock from all the openings shows some copper, but there is much barren quartz on the dumps, especially at the south workings.

Since the last work was done, about three years ago, the shaft house and mining plant have been destroyed by fire.

CHROMITE IN DEER CREEK CANYON.

About 16 miles southwest of Glenrock and 13 miles due south of Big Muddy (see Pl. V), there is a deposit of chromite from which several lots of ore have been shipped. The locality is on the west side of Deer Creek about 400 feet above the bottom of the steep-walled canyon, here about 1,000 feet deep. This district is one characterized by hornblende schists, coarse granites, and scattered masses of serpentine. The chromite is associated with a small serpentine body. It is said that there are several separate masses of the ore, but this the writer did not observe, as because of the steepness of the slope he was able to examine only the upper or western edge of the serpentine area. Along this edge the serpentine is flanked by schist, the wall striking nearly north and dipping steeply to the east. Near the wall and in a general way parallel with it is a layer of ore, which, as shown by a series of pits, has a thickness of 2 to 5 feet and seems to be continuous for a distance of perhaps 150 feet. The ore is dense and fine grained, the chromite being rather evenly intermixed with a scaly silicate mineral that is probably talc. Near the principal chrome-ore pit a layer of gray talc rock has been exposed. Analyses of the ore are here given through the courtesy of Mr. E. W. Merritt, president of the Chromium Mines Co., and of Mr. J. S. Diller, in charge of chromite statistics for the United States Geological Survey.

Analyses of chrome ore from Deer Creek.

	1	2	3
Chromic oxide	42.36	35.16	44.81
Iron	....	20.29	20.87
Alumina	17.16	11.20	....
Lime	....	1.68	....
Magnesia	12.67	13.52	....
Silica	5.72	8.64	3.7

1, 2, Samples sent to Illinois Steel Co.; 3, concentrates furnished by Colorado Fuel & Iron Co.

Carload lots of the Deer Creek ore are reported to have carried 35 per cent of chromic oxide. The freight rate on ore of this class from Glenrock to Chicago is stated by Mr. Merritt to be $4 a ton.

ASBESTOS PROSPECTS EAST OF DEER CREEK.

For several years there has been considerable interest in the development of asbestos deposits on the Casper Range, 8 miles south, and on Smith Creek, 20 miles south of Casper. These districts lie west of Deer Creek.[1] The Smith Creek area extends across Deer Creek, where serpentine rocks are irregularly distributed in masses of small or moderate size over a northeastward-trending area about 8 miles long and 4 miles wide. Although the serpentine areas have been prospected and asbestos has been found in several places, such explorations as were visited are thought to offer little promise. Further developments are not likely to be undertaken until the Smith Creek and Casper Mountain enterprises have been put on a basis of profitable operation.

MORMON CANYON PROSPECTS.

Asbestos and copper locations made by C. J. Wells and associates in Mormon Canyon, at the head of Dry Creek, about 8 miles south of Glenrock, were under development during the summer of 1914. The locality was visited during the temporary absence of Mr. Wells, and the writer was not successful in an attempt to find the copper locations. Samples of the ore that were seen at Douglas show chalcocite and chalcopyrite in white quartz and resemble ore from the Copper King mine.

MARTIN SMITH COPPER PROSPECT.

A mining claim known as the Martin Smith is about 9 miles due south of Glenrock (see Pl. V), in a narrow canyon near the head of a tributary of Hunton Creek. The rocks in the vicinity are hornblende schist, granite, and serpentine. At a point about 100 feet above the bottom of the canyon copper carbonate was discovered. A shaft about 30 feet deep was sunk, and though nothing of practical significance was disclosed a tunnel was run through hornblende schist to a point approximately under the shaft.

LA PRELE DISTRICT.

LOCATION AND GEOLOGY.

The section here called the La Prele district is named for convenience to include mining prospects in the vicinity of the La Prele reservoir, which lies about 12 miles southwest of Douglas. The region is one in which hornblende schists are rather more abundant

[1] Diller, J. S., The types, modes of occurrence, and important deposits of asbestos in the United States: U. S. Geol. Survey Bull. 470, pp. 512-516, 1911.

than granite. In general it is limited on the north by the Paleozoic sedimentary formations, though locally these are overlapped by the Tertiary White River beds. Prospecting has been done in several places, but only two localities were visited.

COPPER PROSPECTS ON COTTONWOOD CREEK.

A group of mining claims 8 miles due south of Careyhurst station, formerly known as the Spring Canyon or Devoe group, is now called

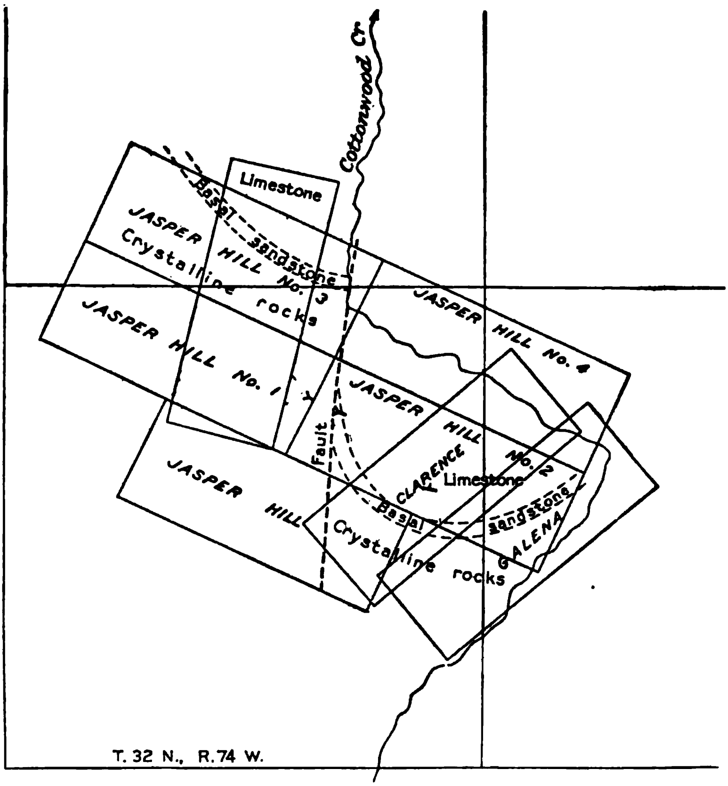


FIGURE 6.—Sketch map of Mewis property, showing location of claims and local geology.

the Mewis property. (See Pl. V.) A plat of these claims made available through the courtesy of Mr. Mewis, of Douglas, shows the principal geologic features of the locality (fig. 6).

The Carboniferous Casper formation here overlaps the pre-Cambrian rocks and is so tilted that its beds dip north-northeast. Immediately overlying black and green schists is a bed of sandstone from 20 to 40 feet thick, and above this are layers of massive limestone. These beds are broken by a strong fault that trends almost directly across their strike and has essentially the same course as the

channel of Cottonwood Creek beyond the mountain front. The vertical displacement along this fault is probably more than 100 feet, and the downthrown block is on the east. Because of the northerly dip of the stratified rocks and the manner in which they have been eroded the horizontal offset of the basal sandstone member is about 800 feet. The sandstone is so indurated that it is properly called quartzite. Away from the fault it is nearly white, but as the break is approached from the east the quartzite takes on a deep-red color. This color change is accompanied by a markedly greater induration, and next to the fault the rock presents a vitreous appearance. The ore mined, which contained carbonate minerals and chalcocite, came from shallow workings that extend at least 50 feet away from the fault break, though the fault can not be accurately located at this place. From a point west of the fault and about 60 feet below the level of the surface workings a tunnel was run in with the evident intention of getting beneath the ore, but apparently it did not lead to the discovery of anything of value.

This occurrence of copper is to be distinguished from all that have been described on foregoing pages in that the metalliferous minerals are here segregated in sandstone of Carboniferous age, whereas not only are most of the other deposits in pre-Cambrian rocks, but their nature is such that they can only be regarded as having been formed in pre-Cambrian time. Copper deposits occur in the Hartville district, in eastern Wyoming,[1] in limestones that correspond in age with the Casper formation.

The influence of the fault in localizing the segregation is obvious. If further prospecting is done, the writer's suggestion would be that the quartzite bed is probably the most favorable place for ore. A tunnel driven in a southwesterly direction from a point in the canyon near the big bend would strike the fault, and by following this break to the south the northward-dipping quartzite would be encountered. The limestone near the fault would be partly explored by the tunnel, and if ore were to be found in the quartzite an extension of the tunnel would show whether the fissure is mineralized below the point where it is met by the quartzite layer.

HAZENVILLE PROSPECTS.

About 1900 some widely advertised prospecting was in progress about 2 miles east of the present La Prele reservoir, at a locality still known as Hazenville. The work, consisting of the opening of a shaft and a tunnel, was undertaken because of a small copper-bearing quartz vein occurring in black schist.

[1] Smith, W. S. T., U. S. Geol. Survey Geol. Atlas, Hartville folio (No. 91), 1903.

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FRANKLIN K. LANE, Secretary

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GEORGE OTIS SMITH, Director

Bulletin 627

THE LIGNITE FIELD OF NORTHWESTERN SOUTH DAKOTA

BY

DEAN E. WINCHESTER, C. J. HARES, E. RUSSELL LLOYD, AND E. M. PARKS

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THE LIGNITE FIELD OF NORTHWESTERN SOUTH DAKOTA.

By DEAN E. WINCHESTER, C. J. HARES, E. RUSSELL LLOYD, and E. M. PARKS.

INTRODUCTION.

LOCATION AND EXTENT.

The field described in this report (see fig. 1) is a rectangular area of about 4,900 square miles in Perkins and Harding counties, S. Dak., and includes nearly all the valuable lignite of the State. It extends from the Montana line to the east line of Perkins County, in R. 17 E. of the Black Hills meridian, and from T. 15 N. to the North Dakota State line.

Lignite is present in nearly every part of the field, but in most places the beds are thin and lenticular. Probably the greater part of the South Dakota lignite will never become of more than local economic importance. A few districts, however, contain beds sufficiently thick and persistent to warrant commercial development. Only about 8 per cent of the total area, or approximately 390 square miles, is underlain by lignite having a thickness of 2 feet 10 inches or more.

OBJECT OF THE SURVEY.

In July, 1910, a large part of the public land in Perkins and Harding counties, S. Dak., was withdrawn from entry on the supposition that it probably contained valuable beds of lignite. This action made it impossible for settlers to obtain patents, which would cover underground as well as surface rights, until the land should be examined and classified by the Geological Survey. This report embraces the results of geologic examinations made during the summers of 1911 and 1912, for the purpose of classifying the area as coal land or noncoal land.

PERSONNEL AND ACKNOWLEDGMENTS.

During the summer of 1911 two field parties were engaged in geologic work in northwestern South Dakota. One, under the direction of E. M. Parks, assisted by H. M. Robinson, R. J. Riggs, P. E. Coaske,

and W. C. Van Emon, worked entirely in Harding County (see fig. 1) west of R. 8 E., and the other, under the direction of Dean E. Winchester, assisted by E. Russell Lloyd, Carl B. Anderson, and S. D. Greene, examined an area in Perkins and Harding counties east of and including R. 8 E. In 1912 a party under the direction of C. J. Hares, aided by E. G. Woodruff, E. M. Parks, J. B. Reeside, jr., Stuart St. Clair, and Louis R. Roark, and another in charge of E. Russell Lloyd, assisted by Burton W. Clark, W. T. Thom, jr., and L. M. Neuman, spent a portion of the field season in completing the examination of Harding and Perkins counties, respectively.

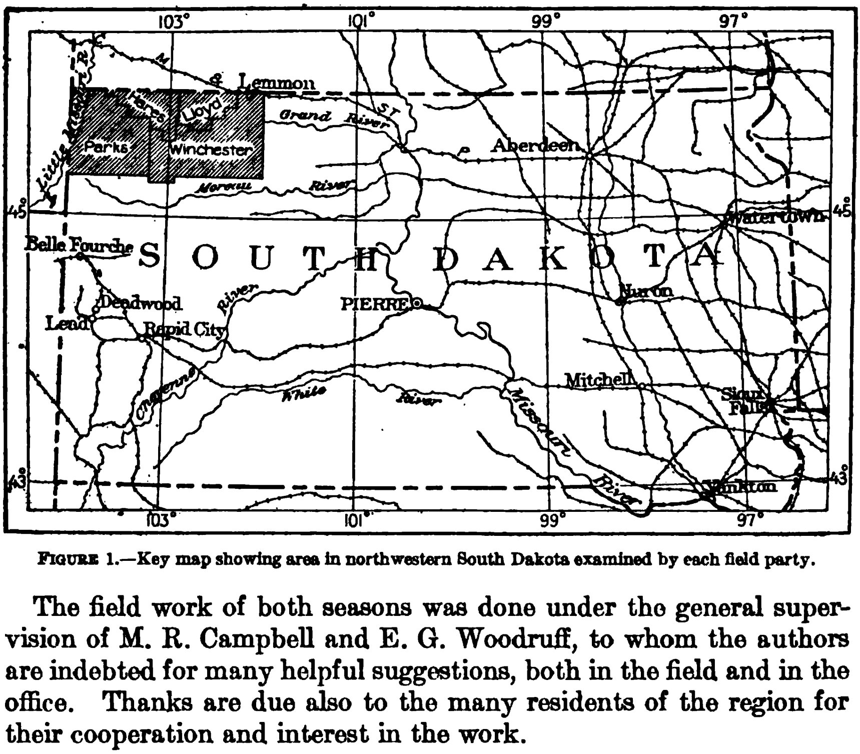

FIGURE 1.—Key map showing area in northwestern South Dakota examined by each field party.

The field work of both seasons was done under the general supervision of M. R. Campbell and E. G. Woodruff, to whom the authors are indebted for many helpful suggestions, both in the field and in the office. Thanks are due also to the many residents of the region for their cooperation and interest in the work.

PREVIOUS WORK.

The first geologist to visit the field was Mr. N. H. Winchell, who accompanied Capt. Ludlow, in 1874, in the military exploration of the Black Hills, and the results of his observations, in the form of an interesting and suggestive journal, are given as a part of the report of the expedition.[1] J. E. Todd, State geologist of South Dakota, in 1893, made a reconnaissance trip into the region to investigate the

[1] Winchell, N. H., Report of a reconnaissance of the Black Hills of Dakota, made in the summer of 1874, by William Ludlow, pp. 21-66, map, 4°, Washington, 1875; U. S. A. Chief of Engineers Rept., 1874, Appendix PP, pp. 1131-1172, Washington, 1875.

lignite, and the data he obtained were published by the South Dakota Geological Survey.[1] Darton[2] has given a summary of the geology of northwestern South Dakota, quoting freely from the reports of Todd and Winchell. Other brief references to this region appear in various reports listed in the bibliography on pages 164–165.

LAND SURVEY.

The area included in the northwestern South Dakota lignite field was surveyed for the General Land Office in the decade 1885–1895. The land corners were marked in some parts of the field by wooden stakes and the regulation pits, but in the greater part by marked stones and pits in place of stakes. Most of the stakes have been destroyed, but the pits and stones remain, so that there is seldom any difficulty in determining the exact location of a corner, except where the markings have been destroyed by roads or cultivation. The surveys of the General Land Office were found to be accurate, so far as could be determined by the methods used in this examination.

FIELD WORK.

The investigation was undertaken primarily to collect data upon which to classify public lands with regard to their mineral or non-mineral character, and it was therefore necessary to locate all data collected with reference to legal subdivisions. In most cases a rapid reconnaissance was first made in each township to determine whether or not lignite was present. During such a reconnaissance the formation boundaries were mapped by plane-table methods or by pacing, and observations were made on the structure and character of the strata. If no lignite beds of sufficient thickness to justify mapping were discovered, further work was not considered necessary. If the preliminary examination revealed lignite beds of importance, they were prospected and measured where possible every thousand feet or so along their outcrop, and the location of such prospects, as well as the position of the outcrop of the beds with reference to section corners, was determined by the use of plane-table methods. Usually in order to make more exact correlations of the scattered exposures, the altitude of each exposure of a lignite bed having a thickness of more than 2 feet was determined by the use of vertical-angle readings in connection with the stadia traverse or single plane-table location. The altitudes of a large number of points along the geologic contacts were also determined, and these were used in interpreting the geologic structure. The altitudes are based on a United States Geological Survey bench mark in T. 12 N., R. 7 E., of the Black Hills meridian;

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[1] Todd, J. E., A reconnaissance into northwestern South Dakota: South Dakota Geol. Survey Bull. 2, p. 43, 1898.

[2] Darton, N. H., Geology and underground waters of South Dakota: U. S. Geol. Survey Water-Supply Paper 227, 1909.

on the altitudes of the Chicago, Milwaukee & St. Paul Railway at Ives, N. Dak., and Lemmon, S. Dak., and on the United Sates Coast and Geodetic Survey's primary bench marks on Table Mountain, Lodgepole Buttes, Slim Buttes, and Short Pine Hills. During the examination a complete map of each township, on a scale of 2 inches to 1 mile, was made and the accompanying maps (Pls. I and II, in pocket) are the result of a compilation of these township maps. The data given on the township plats of the General Land Office were used for platting the land net on plane-table sheets to be used as base maps for the field work.

GEOGRAPHY.

SURFACE FEATURES.

The field described in this report lies in the Great Plains province north of the Black Hills. The region is a rolling, grass-covered prairie, interrupted here and there by small areas of badlands or by steep-sided, flat-topped buttes and ridges. The area south of Grand River and east of the Slim Buttes has long been known to the ranchers of northwestern South Dakota as the "Big Meadow," inasmuch as it has furnished an abundance of hay and excellent grazing for large herds of cattle and horses. Between the northern edge of the Big Meadow and the South Fork of Grand River recent erosion has dissected the area, forming a hilly country known locally as "The Breaks," in which some of the best rock exposures occur. North of the South Fork of Grand River the surface is more undulating but for the most part is covered by grass, so that rock exposures are scarce.

The Slim Buttes, near the center, and the Short Pine Hills, near the southwest corner of the field, are timber-covered mesas rising 300 to 500 feet above the surrounding country. The lower land bordering the cliffs of these buttes has been carved by erosion into intricate badlands with impassable gullies and ridges. The Cave Hills (see Pl. III, *A*), a group of level-topped timbered ridges, small mesas, and disconnected buttes, cover a considerable area in the northern part of the field and are capped by thick beds of yellow and pinkish sandstone which on weathering gives rise to a peculiar honeycomb structure with many small caves. The height of the hills above the general level is 400 to 500 feet. Slumping is much less common than it is about the Slim Buttes and Short Pine Hills.

The red baked rock and clinker resulting from the burning of lignite beds are very resistant and cap sharp cones, buttes, ridges, and small mesas or crop out in low ridges along divides. Their bright colors present a pleasing variation in an otherwise rather dull, monotonous landscape. In northwestern South Dakota clinker

A. WEST FACE OF SOUTH CAVE HILLS, HARDING COUNTY, S. DAK.

B. LANDSLIDE BEDS OF WHITE RIVER FORMATION NORTH OF SLIM BUTTES, HARDING COUNTY, S. DAK.

Thickness of beds included in the slide about 125 feet.

buttes are best developed in the northern part of Harding County, near the Cave Hills, and in Tps. 21 and 22 N., R. 1 E.

Along the small streams, where erosion is so rapid that vegetation can not maintain a foothold, there are many small areas of badlands, where the bare slopes expose all the strata in detail. Such an area, known locally as the "Jump-off," lies along the north side of the divide between Moreau River and the South Fork of Grand River, in Rs. 4 and 5 E., and along the east side of the divide between the Little Missouri and the South Fork of Grand River. It extends from the Short Pine Hills to the south side of T. 20 N., R. 3 E., where it gradually gives way to a rolling prairie. The "Jump-off" badland ranges in width from half a mile to 3 miles and forms a marked contrast with the slopes on the south and west sides of the divide.

Locally there are areas of sand dunes, particularly between the South Fork of Grand River and the East Short Pine Hills.

The altitude of the field ranges from about 2,100 feet above sea level in the valley of Grand River, at the east border of the field, to 3,607 feet on Table Mountain, 3,222 feet on the Lodgepole Buttes, 3,624 feet on the Slim Buttes, and 4,019 feet on the West Short Pine Hills, giving a maximum relief of about 1,900 feet.

DRAINAGE AND WATER SUPPLY.

Three large streams receive the drainage from this field—Little Missouri, Grand, and Moreau rivers.

Little Missouri River, which enters the field from the southwest, flows northward across the western part of Harding County, receiving the drainage of a strip of country about 12 miles in width. Its principal tributaries are Valley and Big Boxelder creeks. The river contains running water at all times, although in dry years the flow is very small. Its valley is broad and open, and the stream meanders over a flood plain about a mile in width.

The South Fork of Grand River is formed by the confluence within a short distance of six perennial streams—Bull, Jones, Buffalo, Sand, Squaw, and Big Nasty creeks. In the eastern part of the area it is joined by the North Fork of Grand River. Its flow is generally less than that of Little Missouri River, but it is scarcely ever dry. In Perkins County the river occupies a broad, open valley cut from 300 to 400 feet below the average level of the Big Meadow to the south, and its many tributaries, which enter at nearly right angles, occupy narrow, steep-sided valleys. Near the river itself are low, sandy hills and broad, sandy flats, whereas away from the stream, in eastern Harding and Perkins counties, the divides are in many places capped by small rocky buttes.

Moreau River, through its tributaries, Antelope, Rabbit, and Thunder Butte creeks, drains most of the Big Meadow and a large

area southwest of the Slim Buttes. The North Fork of Moreau River rises in the southwestern part of the field, but east of range 8 its course is wholly outside of the area.

The many small streams tributary to the Little Missouri and to the South Fork of Grand River have a tendency to flow in northwest or southeast directions. This trend of stream courses is markedly parallel to the strike of the rocks and may have been determined by the rock structure. All the perennial streams and many of the intermittent streams meander on scales commensurate with their size, many of them with almost diagrammatic regularity.

The waters that flow eastward in western South Dakota have a much shorter course to the Gulf of Mexico than those which flow by way of Little Missouri River; in fact, the distance from western Harding County down Little Missouri and Missouri rivers to Fort Pierre, S. Dak., is nearly twice as great as the distance by way of Grand River. This difference produces a much steeper gradient and much more active erosion in the valleys of the eastward-flowing streams. The bed of the South Fork of Grand River at Buffalo is nearly a hundred feet lower than that of Little Missouri River at Camp Crook, about 12 miles to the west, although the latter is a much larger stream. Doubtless if conditions remain as they are at present Little Missouri River will in time be captured by Grand River, as its headwaters 50 miles above have been captured by Belle Fourche River.[1] Erosion at the head of one of the eastward-flowing tributaries of the South Fork of Grand River may in time cut through the present divide between the two rivers and make this capture possible. The waters of the Little Missouri will then flow along what is now Valley Creek for a distance of 3 or 4 miles and cut across the present divide in a general eastward direction, joining the south fork of Grand River near Buffalo.

Throughout the field water for domestic use and for stock is obtained chiefly from shallow wells, although there are a number of good springs. In the open plains area springs are scarce, and the water, which in most places issues from lignite beds, is not especially good. Along the margin of the Slim Buttes, however, there are a number of good springs which issue near the base of the White River formation. The best known of these springs is near the old L ranch, in sec. 29, T. 18 N., R. 8 E., where an abundant supply of pure, cool water flows from a sandy shale near the base of the buttes. Other good springs, issuing from about the same horizon, have been known and used by the stock ranchers for many years. In Cave Hills and Lodgepole Buttes are good springs which also have had an

[1] Darton, N. H., Preliminary report on the geology and underground water resources of the central Great Plains: U. S. Geol. Survey Prof. Paper 32, p. 189, 1905.

important part in the stock-raising history of the country. No artesian water has been developed, and in general the prospect of developing artesian water in the field is not good, as the sandstones are not persistent over sufficiently large areas. According to Darton [1] the head of water from the sandstones of the Benton shale or from the Dakota sandstone, which are the main water-bearing formations of the Black Hills, would be insufficient to produce a flowing well in this area. A well in the Little Missouri flat at Camp Crook was drilled to a depth of 1,100 feet and no flow of water was obtained. At this place the Pierre shale is within 100 feet of the surface, and it is probable that this well did not reach the water-bearing formations or even go completely through the Pierre shale. No water could be expected before the Pierre is passed through, which would mean a depth of 1,400 to 1,700 feet at Camp Crook.

Some of the flats along the larger streams are irrigated by damming smaller tributary valleys to catch the spring wash, and at Willett water is pumped from the river to the terrace by steam power. Both methods are found profitable and may become more profitable with improved appliances.

CLIMATE AND VEGETATION.

Perkins and Harding counties are located in the semiarid area of the Great Plains, where the annual rainfall is about 15 inches and this often falls at seasons when it is least needed. During several years previous to 1910 the rainfall was sufficient to produce an abundant growth of vegetation over a large part of the Big Meadow, and the native grass is reported to have stood knee-high in many places. A large part of the area was originally an open prairie and is destitute of trees, except for a few willows and cottonwoods along stream courses and pines on the buttes. Most of the land can be cultivated and by the use of proper methods of cultivation should yield good crops. The soil constituents are such that only a small amount of moisture is necessary to raise potatoes and other garden vegetables, as well as certain small grains. Not infrequently promising fields of grain are parched in a few days by dry winds or beaten down by hailstorms.

The Slim Buttes, Short Pine Hills, and Cave Hills are included in the Sioux National Forest and are clothed with a scanty growth of yellow pine (*Pinus ponderosa*) and cedar. The pines are far larger and more abundant than the cedars. At present only dead timber may be removed from the national forest, and this only by permission of the forest ranger.

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[1] Darton, N. H., Geology and underground waters of South Dakota: U. S. Geol. Survey Water-Supply Paper 227, p. 77, 1909.

SETTLEMENT.

Several large cattle and horse ranches were established in the area in the early eighties, but recently most of them have given way to small farms. Since 1908 the field has been settled rapidly, so that in 1912 there were very few sections of land that had not been entered by the homesteader.

Lemmon, on the Chicago, Milwaukee & St. Paul Railway, is the largest town in the area, having, according to the last census, a population of 1,200, and is a distributing point for a large section of the surrounding country. Meadow, one of the older towns of the region, is the distributing point for mail for the near-by towns and is connected with Lemmon by a daily automobile stage. Bison, the county seat of Perkins County, is a town of about 100 inhabitants in sec. 13, T. 18 N., R. 13 E., and is connected with the railway at Lemmon by daily stage going through Meadow. Strool, in sec. 19, T. 18 N., R. 11 E., a thriving business town of about 75 inhabitants, is the distributing center for a large area and is connected with Hettinger, N. Dak., by daily automobile stage. Camp Crook, with 125 inhabitants, is located on Little Missouri River 6 miles north of the West Shore Pine Hills, and is on a stage line between Belle Fourche, S. Dak., on the Chicago & North Western Railway, and Bowman, N. Dak., on the Chicago, Milwaukee & St. Paul Railway. Buffalo, the county seat of Harding County, in sec. 30, T. 19 N., R. 5 E., has a population of about 100 and is on another stage line connecting Belle Fourche and Bowman. Each of the remaining places indicated on the maps (Pls. I and II, in pocket) consists of a few houses with a store or two and a post office, or of a ranch house that serves as a post office.

In addition to the main stage roads, there are numerous other roads which give easy access to all parts of the field except those immediately adjacent to the high mesas. Roads are being rapidly adjusted to section and township lines, and it was not deemed advisable to show their present locations on the map. The Chicago, Milwaukee & St. Paul Railway, the only railway which enters the field, crosses only the northeastern corner. During 1910 a survey was made for an extension of a branch line of this road from Isabel and Firesteel, east of the field, across Perkins County near Chance, Daviston, and Sorum. No construction work, however, has yet been done on this line.

GEOLOGY.

GENERAL OUTLINE.

The stratigraphic section exposed in the northwestern South Dakota lignite field includes rocks of Cretaceous, Tertiary, and Quaternary age. The oldest rocks belong to the upper part of the Pierre shale, which

is of marine origin, and are succeeded by the Fox Hills sandstone, also marine. This is in turn overlain by the predominantly fresh-water shale and sandstone of the Lance formation.

In the field two members of the Lance formation are recognized in addition to a lower undifferentiated part. The upper one is the Cannonball marine member, of which, however, the distribution in northwestern South Dakota is not definitely known. It is known to extend across the northern part of Perkins County and at least a part of Harding County. The type locality of the member is on Cannonball River in Morton County, N. Dak., and the member has been described by Lloyd[1] and later by Lloyd and Hares.[2]

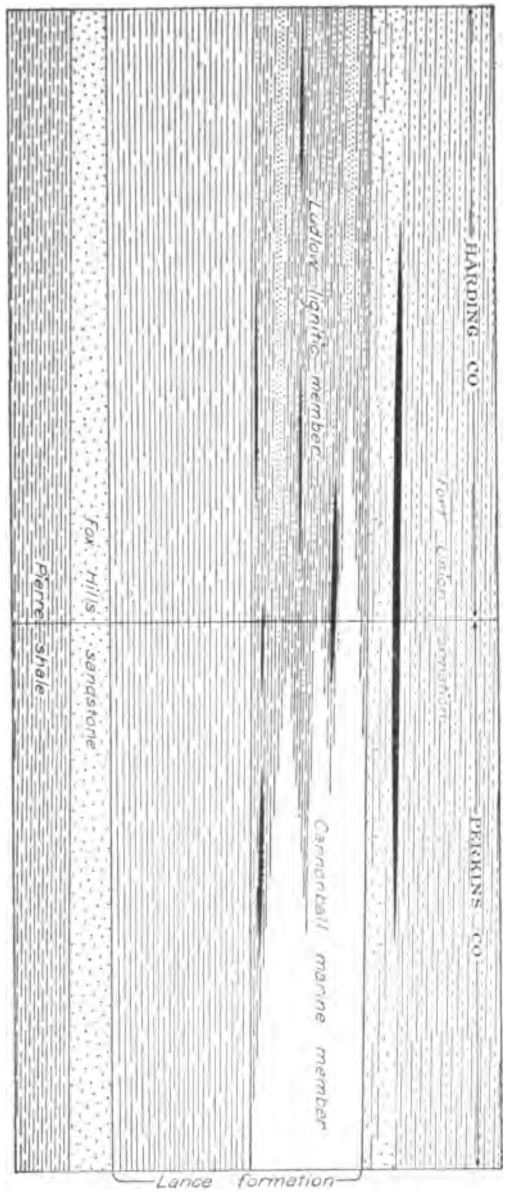

FIGURE 2.—Diagram showing the interrelation of the members of the Lance formation.

In the western part of the field the Ludlow lignitic member underlies the Cannonball and is typically developed in the vicinity of Ludlow, Harding County. In the eastern part of the field the Ludlow member is thinner and the Cannonball thicker, and the two are therefore probably in part of the same age. The authors' interpretation of the conditions of sedimentation is illustrated by the accompanying diagram (fig. 2).

[1] Lloyd, E. R., The Cannonball River lignite field, N. Dak.: U. S. Geol. Survey Bull. 541, pp. 243–291, 1914.

[2] Lloyd, E. R., and Hares, C. J., The Cannonball marine member of the Lance formation of North and South Dakota and its bearing on the Lance-Laramie problem: Jour. Geology, vol. 23, pp. 523–547, 1915.

The predominantly light-colored sandstone and shale of the lignite-bearing Fort Union formation overlie the Lance and are apparently conformable with it. Rocks of Oligocene and possibly Miocene age form a number of prominent buttes and rest unconformably on both the Lance and Fort Union formations. Quaternary deposits are represented by dune sands, by the present flood plains of the principal streams, and by old river terraces from 50 to 75 feet above the present valley floors.

A general geologic section is given below.

Generalized section of the geologic formations in northwestern South Dakota.

System.	Series.	Formation and member.		Thickness in feet.	Character.
Quaternary.					Sand dunes, terrace and flood-plain deposits.
Tertiary.	Miocene (?).	Arikaree (?) sandstone.		75-225	Thick-bedded gray to greenish-white calcareous sandstone, generally fine grained. Contains many fragments of acidic volcanic rocks. Weathered surface in places shows concretionary structure.
		Unconformity(?)			
	Oligocene.	White River formation, including both Titanotherium and Oreodon zones.		45-140	Banded and flesh-colored calcareous clays, with siliceous nodules and irregular plates in upper half and coarse white calcareous sandstone in lower half. Locally cross-bedded on large scale.
	Unconformity, both angular and erosional. At least 750 feet of rock strata removed.				
	Eocene.	Fort Union formation.		425	Massive fine-grained yellow sandstone, shale, and lignite.
Tertiary(?)	Eocene (?).	Lance formation.	Cannonball marine member.	0-225	Dark fine-grained sandstone and shale.
			Ludlow lignitic member.	0-350	Yellowish to gray sandstone, clayey sandstone, shale, and lignite beds, variable in thickness and quality.
				425	Somber-colored soft shale, brown shale, and gray sandstone, with thin lignite lenses in upper part. Lower half more sandy and contains few lignite or bituminous bands. Many concretions and thin lenses of iron carbonate. Loglike concretions. Extremely variable throughout.
Cretaceous.	Upper Cretaceous.	Fox Hills sandstone.		25-75	Marine grayish-white to yellowish friable sandstone, with concretions.
		Pierre shale.		50 exposed.	Marine dark shale containing oval limestone concretions that break into rhombs when exposed to weather. Gives rise to gumbo soil.

CRETACEOUS SYSTEM.

PIERRE SHALE.

The Pierre shale crops out in a small area near the extreme southwest corner of the field, where only about 50 feet of the formation is exposed. According to Darton,[1] its total thickness in this region is 1,200 to 1,400 feet. The record of a well at Camp Crook shows that the Pierre is within 100 feet of the surface at that place.

The formation is made up of drab to black soft, crumbly shale, which is very fine grained and apparently homogeneous throughout, with the exception of scattered concretions, which are nonfossiliferous. The cone-in-cone structure is common in most exposures. Gypsum is abundant, occurring as small crystals in the shale, and is the cause of much of the alkali in the water flowing over this formation. The weathered outcrops of the formation are ashen, tan, or light brown in color and extremely porous, but in fresh outcrops along stream channels the shale appears nearly black and is so soft that it may be easily carved into blocks with a knife. Structurally it is thinly bedded and jointed.

The Pierre shale weathers into a somewhat barren rolling and uninviting country, commonly known as the "gumbo country." Its areas are distinguished topographically by smooth, rounded hills, gentle slopes and valleys, and a general absence of peculiar erosion forms such as characterize areas of the Lance formation. The soil when dry is loose and often deeply cracked, but when wet it is very sticky and boggy. For agricultural purposes soil derived wholly from the Pierre is very poor, being usually alkaline and infertile. Such vegetation as grows on it appears to be stunted, and much of the ground is barren.

No fossils were collected from the Pierre in the area covered by this report, but elsewhere it carries a large marine fauna, as cited by Darton.[2] Calvert,[3] Leonard,[4] and others.

FOX HILLS SANDSTONE.

The Fox Hills sandstone overlies the Pierre shale south of the Short Pine Hills and is exposed along the axis of the low Glendive anticline along the North Dakota State line east of Little Missouri River. South of the Short Pine Hills the formation consists of 25 feet or more of very friable yellow to gray medium-grained sandstone, with concretions showing cross-bedding. The upper limit of the

[1] Darton, N. H., op. cit., p. 23.

[2] Idem, p. 41.

[3] Calvert, W. R., Geology of certain lignite fields in eastern Montana: U. S. Geol. Survey Bull. 471, pp. 192-194, 1912.

[4] Leonard, A. G., The geological history of North Dakota: North Dakota Geol. Survey Fifth Bienn. Rept., pp. 227-243, 1908.

formation can not be ascertained with accuracy in this part of the field, owing to the grass-covered character of the country.

In the area along the North Dakota State line only 30 or 40 feet of the formation is exposed and the upper limit is fairly distinct. The formation consists of very light gray or almost white sandstone, composed of rather fine grains of white quartz and a small amount of black mica, the whole weakly cemented by calcium carbonate. This area is at the south end of the Glendive anticline, and the sandstone has been included in the Colgate sandstone member of the Lance formation, as mapped around the same anticline farther northwest.[1] Shark teeth and the marine plant *Halymenites major* occur abundantly in the formation in North Dakota.[2] Fossil leaves were collected in T. 23 N., R. 2 E., from ferruginous concretions on the surface of the formation, but these concretions may have been washed down from the overlying Lance.

Although the Fox Hills is only 25 to 75 feet thick in this area and is 300 to 400 feet thick in the type locality at Fox Ridge, S. Dak., 200 miles to the east, the difference may be due to unequal deposition and not to unequal erosion, as the sandstone represents a shore phase of deposition.

It does not appear that in this region there was any profound break in sedimentation, either at the beginning or at the end of Fox Hills time. The exposures are so poor as to preclude the detection of discordance of strikes and dips or evidence of erosional unconformity, but if there was a hiatus, it was one in which little or no erosion occurred.

The sandstone is assigned to the Fox Hills formation on the grounds that in this field, as in the type locality about 200 miles to the east, the Fox Hills occurs conformably immediately above the Pierre; lithologically it is similar to the Fox Hills in its type area; and the formation in North Dakota, with which this area is directly connected, bears marine fossils (shark teeth and *Halymenites major*) and a few Cretaceous invertebrates.

TERTIARY (?) SYSTEM.

LANCE FORMATION.

GENERAL CHARACTER.

The Lance formation, so far as observed, rests conformably on the Fox Hills sandstone. The beds of both formations lie almost horizontal and no discordance of dip and strike is noticeable. The Lance consists of three parts: (1) A lower part lithologically and faunally similar to the Lance in other fields near by; (2) the Lud-

[1] Calvert, W. R., op. cit., pp. 189, 194-195.

[2] Hares, C. J., Lignite in southwestern North Dakota: U. S. Geol. Survey Bull. (in preparation).

low lignitic member, 0 to 350 feet thick, lithologically and florally similar to the Fort Union; and (3) the Cannonball marine member, 0 to 225 feet thick. Figure 2 (p. 15) shows the relations of these divisions of the Lance to one another and to the Fox Hills and Fort Union formations. The three parts of the formation are variable in character, and the change from the prevailing somber shale of the lower part to the more yellow sandstone or sandy shale of the Ludlow member is well defined in some parts of the field and gradual in others.

The lower part of the Lance weathers into badlands and into rounded buttes and ridges, whereas the weathering of the Ludlow member produces flat-topped buttes capped by sandstone.

LOWER PART OF THE LANCE FORMATION.

The lower part of the Lance is the surface formation over a very large part of the field. It occupies practically the whole of Harding County south and west of the Slim Buttes, Cave Hills, and Table Mountain, with the exception of the Short Pine Hills and the small areas of Pierre shale and Fox Hills sandstone. In Perkins County it outcrops in a broad zone along the south and east margins of the field and is exposed along the valley of the South Fork of Grand River.

The maximum thickness (about 425 feet) of the lower part of the Lance occurs south of the Slim Buttes, in Tps. 15 and 16 N., R. 8 E. This part of the formation consists predominantly of somber-colored sandy shale, but contains local lenses of fine-grained gray and yellow sandstone and thin beds of lignite of varying quality. Iron carbonate, which weathers to limonite, occurs in the shale as concretions and as thin lenses. The yellow sandstone contains marcasite concretions and "log concretions."

The upper limit of the lower part of the Lance is placed at the horizon where the prevailingly somber-colored shale is succeeded by the prevailingly yellow sandy strata. The horizon is in many places marked by a bed of lignite. That part of the formation lying below the horizon as a rule is nonlignitic and all the dinosaur remains collected during the field examination were found in it.

The lower part of the division as a whole is barren of economically important lignite beds and contains very little, if any, rock suitable for building stone. Near the top of this division several small and for the most part thin lenses of lignite were found, one of which is more than 4 feet thick over a considerable area in T. 21 N., R. 5 E.

LUDLOW LIGNITIC MEMBER.

Rocks assigned to the Ludlow lignitic member of the Lance formation occur in the western part of the field, as outliers, as a thin covering of the divides, and as belts around the higher buttes and mesas.

In the eastern part they underlie large areas along the divide between Moreau River and the South Fork of Grand River, and from the latter stream northward to the State line.

The Ludlow lignitic member is named from the town of Ludlow, in Harding County, where it is well exposed. Its thickness in this part of the field is from 300 to 350 feet, but it is thinner toward the east and has not been recognized east of the field. The Ludlow member is distinguished from the underlying Triceratops-bearing portion of the Lance by a generally lighter color and a greater amount of sandstone and lignite. Lithológically it is very similar to the Fort Union formation, but it is separated from that formation throughout at least a part of the field by the marine Cannonball member.

The Ludlow lignitic member, in its type locality, consists of interbedded light-colored sandstone and shale of varying composition and lignite. There are all gradations between a true shale and a quartz sandstone. As in the lower part of the Lance, by far the greater proportion of the rock is loosely consolidated and easily disintegrated. The following stratigraphic sections show the character of the Ludlow member fairly well:

Composite sections of part of the Ludlow lignitic member of the Lance formation.

Section in secs. 32 and 36, T. 22 N., R. 5 E.

Top of mesa.	Ft.	in.
Sandstone, yellowish, and shale (Fort Union formation)	255	0
Lignite		8
Sandstone, somewhat shaly	45	0
Shale, dark	2	0
Lignite	2	4
Sandstone, light colored, grayish, argillaceous	12	0
Sandstone, buff with ferruginous specks	15	0
Lignite		2
Sandstone, buff, fine grained, muscovitic	11	0
Lignite		3
Sandstone	8	0
Lignite		6
Sandstone, buff	25	0
Shale, bluish	1	0
Shale, carbonaceous		10
Shale, arenaceous	5	0
Lignite		1
Sandstone, buff, soft	5	4
Sandstone	1	0
Shale, arenaceous, with carbonaceous streaks	4	0
Sandstone, argillaceous	6	0
Lignite	1	0
Concealed	22	0
Sandstone, drab, cross-bedded, ripple-marked	3	0
Shale, arenaceous	4	0
Lignite	1	5

Composite sections of part of the Ludlow lignitic member of the Lance formation—Con.

Section in secs. 32 and 36, T. 22 N., R. 5 E.—Continued.

	Ft.	in.
Shale, brown	3	0
Lignite	2	1
Shale, dark		5
Lignite		8
Shale	1	3
Lignite	1	5
Shale, brown	4	0
Lignite	2	3
	191	8

Section in T. 20 N., R. 9 E.

	Ft.	in.
Sandstone, yellow, medium fine grained, capping hills	20	0
Shale, brown	3	0
Lignite	1	0
Shale, brown		6
Sandstone, yellow	16	0
Shale, brown	1	10
Lignite, dirty		8
Shale, brown	3	0
Shale, black		8
Lignite, dirty		6
Shale, brown	1	6
Sandstone, buff to yellow	12	0
Shale, brown	2	0
Shale, black		4
Lignite		8
Sandstone and shale, with lignite streaks	13	6
Lignite		8
Shale		3
Lignite	3	6
Shale, brown, arenaceous	1	0
Sandstone.		
	82	7

Section in T. 21 N., R. 7 E.

	Ft.	in.
Top of "Two Tops."		
Sandstone and shale (Fort Union formation)	138	0
Shale, chocolate-colored	2	0
Sandstone, buff and yellow, fine grained, alternating with buff shale	9	0
Shale, chocolate-colored	3	4
Lignite	1	0
Shale, buff and yellow sandstone, alternating	16	0
Shale, chocolate-colored	3	0
Sandstone, brown, fine grained	2	6
Shale	10	0
Lignite, Giannonatti bed	11	8
Sandstone, light, argillaceous	16	4
Shale, brown	3	0
Lignite	4	2

Composite sections of part of the Ludlow lignitic member of the Lance formation—Con.

Section in T. 21 N., R. 7 E.—Continued.

	Ft.	in.
Shale	13	0
Lignite	3	8
Shale and sandstone	15	0
Lignite	3	4
Shale, carbonaceous		6
Shale.		
	117	6

Section in sec. 36, T. 21 N., R. 6 E.

	Ft.	in.
Sandstone, light buff, fine grained	16	0
Giannonatti bed: Lignite	3	10
Giannonatti bed: Shale		2
Giannonatti bed: Lignite	5	4
Giannonatti bed: Shale, brown		3
Giannonatti bed: Lignite	1	6
Shale, brown	10	0
Lignite		10
Sandstone ?, mostly concealed	42	0
Shale	15	0
Lignite, Widow Clark bed	4	1
Shale, brown	6	0
Sandstone and shale	25	0
Lignite	1	0
Shale	5	0
Lignite, dirty	2	6
	138	6

Lignite beds occur throughout the Ludlow member, but few of them are persistent for more than a few miles along their outcrop. Locally they attain considerable thickness and have been worked to supply a large part of the fuel for the inhabitants of the region. A very large proportion of the lignite in the South Dakota field occurs in the Ludlow member. The thickest and most extensive beds or groups of beds is the T Cross, which occurs near the top of the member, and the Widow Clark.

In the northeastern part of Harding County many stone houses are built of thin, flaggy sandstone from the Ludlow lignitic member of the Lance formation.

CANNONBALL MARINE MEMBER.[1]

The Cannonball marine member of the Lance formation comprises the sediments deposited in the sea which extended over a portion of North and South Dakota after the deposition of the underlying sediments of continental origin. The type locality for this member is on Cannonball River in Morton County, N. Dak., where from 300 to 350 feet of marine beds are exposed. In South Dakota the marine

[1] Lloyd, E. R., and Hares, C. J., The Cannonball marine member of the Lance formation in North and South Dakota and its bearing on the Lance-Laramie problem: Jour. Geology, vol. 23, pp. 523-547, 1915.

member has been recognized in a comparatively narrow zone surrounding the areas of Fort Union rocks in northern Perkins County and in northeastern Harding County. The geographic distribution of the member is not definitely known, for the reason that it is defined almost wholly by its contained fossil fauna and the fossils were found only near the end of the work in the general region of northwestern South Dakota and the limits of the member had not previously been mapped. The limits as shown on Plates I and II (in pocket) were drawn from the known position of lignite beds and from the topography and are only approximate. This member becomes gradually thinner toward the west and has not been recognized west of R. 9 E. The presence of a brackish-water fauna at about the same stratigraphic horizon on Little Missouri River near Yule, N. Dak., however, suggests that the marine sediments extend farther west in North Dakota than in this field.

The only place in northwestern South Dakota where the Cannonball member was examined in detail is near Bloom post office, in T. 23 N., R. 9 E. The following section shows the character of the member and associated beds at this place:

Generalized section in vicinity of Bloom, S. Dak., T. 23 N., R. 9 E.

	Ft.	in
Top.		
9. Sandstone, brown and yellow, fine grained, thin bedded, interbedded with lenses of compact bluish-gray limestone	30	0
8. Sandstone, dark gray, calcareous, marine (fossil collections Nos. 43 and 44)	10	0
7. Shale	1	0
6. Lignite	2	0
5. Shale and sandstone interbedded; sandstone in lower part light brown, medium fine grained, micaceous, marine (fossil collection No. 45)	40	0
4. Lignite	1	0
3. Shale	4	0
2. Lignite	2	3
1. Shale.		
River.	90	3

The beds numbered 5, 8, and probably 9 of the above section belong to the Cannonball member. In addition to the collections of marine fossils mentioned in the section, a few more were obtained in northern Perkins County from the residual bowlders of thin but persistent beds of concretionary limestone.

FOSSILS.

During the two field seasons several small collections of fossils were made in different parts of the field and at different horizons. The plant remains have been studied by F. H. Knowlton, the invertebrates by T. W. Stanton, and the vertebrates by J. W. Gidley.

The following lists show the localities at which the collections were made and the fossils identified from each collection:

Fossils collected from the lower part of the Lance formation.

F 23.[1] NE. ¼ sec. 3, T. 19 N., R. 7 E.
Carpites sp.
Sequoia nordenskioldi (?) Heer.
Nelumbo n. sp.

F 24. NW. ¼ sec. 3, T. 19 N., R. 7 E.
Sequoia nordenskioldi Heer.
Sapindus affinis Newberry.

F 6. SW. ¼ SE. ¼ sec. 33, T. 22 N., R. 3 E.
Ficus ungeri? Heer.

F 55. Sec. 17, T. 21 N., R. 16 E.
Populus cuneata Newberry.
Populus amblyrhyncha Ward.
Celastrus pterospermoides Ward.

F 47. Sec. 7, T. 17 N., R. 11 E. (from roof of Phillips lignite mine).
Grewia celastroides Ward.
Celastrus pterospermoides Ward.
Stems, etc.

F 16. NW. ¼ sec. 2, T. 18 N., R. 5 E.
Triceratops, fragment of skull.
Trachodon.

F 11. NE. ¼ sec. 2, T. 19 N., R. 4 E.
Trachodon, caudal and foot bone, vertebræ.
Aspideretes, costal bone.
Champsosaurus, vertebræ.
Compsemys?
Basilemys?

F. 10. Center of sec. 20, T. 17 N., R. 4 E.
Aspideretes.
Champsosaurus.

F 7. SW. ¼ sec. 26, T. 17 N., R. 3 E.
Champsosaurus.
Leidyosuchus.
Triceratops.
Trachodon.
Compsemys.
Aspideretes.

F 8. Center of sec. 36, T. 17 N., R. 3 E.
Champsosaurus.
Leidyosuchus.
Aspideretes.
Compsemys.
Basilemys.
Trachodon.
Ceratopsian.
Lepisosteus.
Triceratops.

F 9. NE. ¼ NW. ¼ sec. 23, T. 16 N., R. 3 E.
Aspideretes.
Champsosaurus.
Trachodon.

F 38. NW. ¼ sec. 8, T. 15 N., R. 9 E.
Aspideretes.

F 54. Sec. 13, T. 20 N., R. 16 E.
Champsosaurus.
Ornithomimus.

F 5. SW. ¼ NE. ¼ sec. 30, T. 23 N., R. 2 E.
Ornithomimus.
Trachodon.
Champsosaurus.
Aspideretes.

Fossils collected from the Ludlow lignitic member of the Lance formation.

F 28. Sec. 32, T. 18 N., R. 8 E. (from soft shaly sandstone above a lignite bed and about 225 feet above the base of the Ludlow member).
Taxodium occidentale Newberry.
Ginkgo adiantoides? Heer.
Sapindus affinis? Newberry.
Fragmentary leaf.

F 40. Sec. 24, T. 17 N., R. 9 E. (from yellow friable sandstone above a lignite bed near the head of Wolf Draw, about 90 feet above the base of the Ludlow member).
Platanus haydenii Newberry.
Populus amblyrhyncha Ward.
Populus daphnogenoides Ward.
Viburnum sp.

F 50. Sec. 29, T. 17 N., R. 13 E. (from baked shale above lignite bed which occurs at base of Ludlow member).
Carpites sp.
Sapindus affinis? Newberry.
Fern, fragmentary.
Corylus sp.
Celastrus sp.?
Cocculus haydenianus Ward.

F 51. Sec. 17, T. 17 N., R. 13 E. (from shale above lignite at Sexton mine).
Onoclea sensibilis Linné.
Cocculus haydenianus Ward.
Sapindus cf. S. affinis Newberry.
Sapindus grandifoliolus Ward.
Conifer, Taxodium ? sp.

[1] Numbers refer to location numbers on maps.

Fossils collected from the Ludlow lignitic member of the Lance formation—Continued.

F 18. NE. ¼ SW. ¼ sec. 12, T. 17 N., R. 7 E.
- Sequoia nordenskioldi Heer.
- Thuya interrupta Linné.
- Cocculus haydenianus Ward.
- Viburnum sp.
- Populus cuneata Newberry.
- Populus.
- Celastrus pterospermoides Ward.

F 19. Center of sec. 1, T. 17 N., R. 7 E.
- Thuya interrupta Newberry.

F 20. NE. ¼ SE. ¼ sec. 36, T. 18 N., R. 7 E.
- Thuya interrupta Newberry.
- Onoclea sensibilis Linné.
- Viburnum cf. V. elongatum Ward.
- Leguminosites arachioides Lesquereux.

F 22. SW. ¼ SW. ¼ sec. 24, T. 19 N., R. 7 E.
- Sequoia nordenskioldi Heer.
- Sapindus grandifoliolus Ward.
- Celastrus pterospermoides Ward.
- Celastrus curvinervis Ward.

F 14. SE. ¼ SE. ¼ sec. 5, T. 20 N., R. 5 E.
- Sequoia nordenskioldi Heer.
- Sapindus sp.

F 46. NW. ¼ SE. ¼ sec. 32, T. 21 N., R. 10 E.
- Taxodium occidentalis Newberry ?
- Fragments of plant stems.

F 12. Center of sec. 7, T. 22 N., R. 4 E.
- Centrum of vertebra and other fragments of a crocodile of Tertiary aspect. Not determinable.

Fossils collected from the Cannonball marine member of the Lance formation.

F 41. SE. ¼ sec. 14, T. 21 N., R. 9 W.
- Ostrea glabra M. and H.

F 43. Sec. 36, T. 23 N., R. 9 W.
- Fossil wood full of burrows of Teredo-like shell.

F 44. Sec. 24, T. 23 N., R. 9 W., a quarter of a mile from Bloom, on the south bank of the North Fork of Grand River.
- Nucula sp.
- Callista deweyi M. and H.
- Pholos sp.
- Corbula sp.
- Anchura americana E. and S.

F 56. SW. ¼ sec. 11, T. 21 N., R. 14 E., on North Fork of Grand River, 10 miles south of White Buttes, S. Dak.
- Small specimens of Nucula, Crenella, and other small marine pelecypods.

F 57. SW. ¼ sec. 2, T. 22 N., R. 12 E.
- Anchura americana (E. and S.).

F 58. West quarter corner of sec. 11, T. 22 N., R. 15 E., 7 miles southwest of Lemmon, S. Dak.
- Nucula planimarginata M. and H.
- Thracia aff. I. subgracilis Whitfield.
- Lunatia sp.
- Anchura americana (E. and S.).

F 59. East side of sec. 7, T. 22 N., R. 17 E., 8 miles southeast of Lemmon, S. Dak.
- Nucula planimarginata M. and H.
- Leda scitula M. and H.?
- Veniella? sp.
- Tellina? sp.
- Corbula? sp.
- Thracia? sp.
- Anchura americana (E. and S.).
- Fasciolaria (Piestocheilus) culbertsoni M. and H. var.
- Cylichna? sp.

F 60. SW. ¼ sec. 34, T. 23 N., R. 17 E., 9 miles east of Lemmon, S. Dak.
- Nucula planimarginata M. and H.
- Anchura americana E. and S.
- Turris aff. T. contortus M. and H.
- Fragment of crustacean claw.

The evidence of the fauna and flora listed above is somewhat at variance. The flora throughout, according to Knowlton, is Tertiary in aspect and is so much like that of the succeeding Fort Union formation that at present it is impossible to separate the two formations on the basis of fossil leaves. Certain species, however, have been found only in the Lance formation. The flora is distinct from

that found in rocks of recognized Cretaceous age of the Rocky Mountain region, although there are many forms in common.

Some of the fresh-water invertebrates found in adjacent areas [1] are not distinguishable from those found in the overlying Fort Union, and the fresh-water fauna is therefore of little value in determining the age of the Lance. The marine invertebrate fauna, which is confined to the Cannonball member, is very similar to but not identical with the fauna of the Fox Hills sandstone, of recognized Cretaceous age. This fauna is so like that of the Fox Hills that the open sea in which the Fox Hills sediments were deposited must have persisted in no very remote area throughout the time when the lower part of the Lance was being laid down in fresh water. No marine invertebrate fossils have been found in the Fort Union or later formations in this part of the United States, and the value of this fauna in determining the Cretaceous age of the Lance is doubted by many geologists.

The reptilian remains, which were collected almost wholly from the lower part of the formation, are forms that are common to the Lance of other areas. The chief diagnostic fossil, Triceratops, is present in this field, and representatives of the family Ceratopsidæ, to which it belongs, have been found in rocks varying in age from about the middle of the Upper Cretaceous to the end of the Lance epoch, but not in strata of later age.

It is also impossible to settle the question as to the Tertiary or Cretaceous age of the Lance on the basis of evidence of diastrophism. Some evidence of unconformity at the base of the Lance has been observed at a number of places in the Dakotas and in eastern Montana, but the writers do not believe that these unconformities indicate a marked break in sedimentation.

On careful consideration of all the evidence available at the present time the United States Geological Survey has decided to consider the Lance as of Tertiary (?) age.[2]

TERTIARY SYSTEM.

FORT UNION FORMATION (EOCENE).

Rocks of Fort Union age are found mainly north of Big Nasty Creek and the South Fork of Grand River, in the northern three tiers of townships extending from the northeast corner of the field to Table Mountain. Remnants of the formation caps Table Mountain, the Cave Hills, Eagles Nest, and Two Tops Butte and cover other isolated areas.

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[1] Hares, C. J., Lignite in southwestern North Dakota: U. S. Geol. Survey Bull. (in preparation).

[2] The writers, however, are divided in their opinions. Hares and Lloyd are convinced that the Lance is of Cretaceous age; Winchester is equally convinced that it is of Tertiary age. Winchester is of the opinion that the fossil flora presents the most complete and therefore most reliable evidence, inasmuch as leaves are found in Cretaceous as well as Tertiary rocks, and there is a marked difference between the flora of the Lance and Fort Union and that of recognized Cretaceous formations. Hares and Lloyd, on the contrary, are of the opinion that greater weight should be given to the evidence furnished by the marine fauna and the land vertebrates.

The Fort Union formation, which overlies the Lance, is about 300 feet thick, as determined in the southeastern part of T. 22 N., R. 8 E., where the highest Fort Union sediments in the field cap the Lodgepole Buttes. This, however, is probably only a small part of the original thickness of the formation, which at one time probably extended over the entire region.

The rocks, which vary in color from light gray, tan, and buff to brown, are chiefly arenaceous in composition. They are in places argillaceous or carbonaceous and here and there highly calcareous. Nearly all the sediments are partly cemented by calcium carbonate and effervesce freely with weak hydrochloric acid. They are for the most part very fine grained and evenly thin bedded, though in places rather massive.

The basal sandstone of the Fort Union caps the Cave Hills, Eagles Nest, in T. 23 N., R. 5 E., and Table Mountain, the culminating point on the divide between the North and South forks of Grand River and Little Missouri River. To the east it loses its massive character and seem not to be present in the Tepee Buttes or in the butte northwest of Ludlow. The sandstone in places resists erosion to a marked extent and stands out in vertical walls, to which is due the mesa-like character of the Cave Hills and Table Mountain. It is characteristically pitted with cavities ranging from half an inch to a foot or more in diameter, which are formed largely by the wind acting on unequally indurated rock. Here and there water and wind have carved large cavities along joint planes. One of these is locally known as Ludlow's cave. Other smaller caves have served as graves for the Indians. On Eagles Nest the sandstone is somewhat cross-bedded and conglomeratic. The pebbles range from 1 inch to 10 inches in diameter, and some of them are slightly angular. Pine trees show a preference for the loose, sandy soil derived from these rocks, and the limits of the sandstone in the Cave Hills are virtually the limits of the forests.

The two distinct cliffs of the North Cave Hills are formed by two phases of sandstone belonging to the Fort Union formation. The lower sandstone, 75 to 100 feet thick, is yellow to brown in color, coarse to fine grained in texture, and massive in appearance and is composed chiefly of subangular quartz grains and accessory mica. It is weakly cemented by lime and in places is notably cross-bedded. Overlying the lower sandstone in the southern portion of the North Cave Hills is about 20 feet of light-colored or whitish argillaceous sandstone, separating it from the succeeding reddish sandstones. In sec. 27, T. 22 N., R. 5 E., a thin bed of lignite occurs in this interval. The upper sandstone is conspicuously cross-bedded, the cross-beds being from 1 to 8 inches thick and in places 30 feet long. The upper sandstone seems to be free from lime, and its coloring is due chiefly

to iron oxide. It is a soft coarse-grained, somewhat massive rock, composed mostly of rounded grains of quartz and small flakes of muscovite. It is about 135 feet thick. A bed of conglomerate, composed of fragments of soft reddish sandstones, occurs near the top. At several places in the Cave Hills the reddish sandstone is succeeded by a bed of quartzite. The following detailed section was measured in sec. 31, T. 22 N., R. 6 E.:

Section of part of the Fort Union formation in the SW. ¼ sec. 31, T. 22 N., R. 6 E.

	Feet.
Sandstone, pitted	5
Sandstone, white, argillaceous, grading into sandstone, white, fine grained, and soft	91
Sandstone	11
Sandstone, yellow, very fine grained, with white sandstone concretions	70
Sandstone, white, rounded fine quartz grains; soft	32
Shale, Ludlow lignitic member of the Lance formation.	
	209

The Fort Union formation in the region about the Lodgepole Buttes and farther east rests on the Cannonball marine member of the Lance formation and consists of less massive beds than in the Cave Hills, being composed of fissile calcareous and arenaceous rocks. The sandstone is made up of fine quartz fragments cemented by calcium carbonate and is light brown, tan, and buff in color. In places it is ripple marked and somewhat cross-bedded. The indurated sandstones and limestones are interbedded with more or less unconsolidated sandy and clayey beds and lignite.

The indurated beds of sandstone and limestone protect the underlying strata from rapid erosion and give rise to the angular shoulder on the outer edge of the plateau, which surrounds the Lodgepole Buttes and extends eastward to the vicinity of Lemmon.

The following are detailed sections of parts of the Fort Union formation south of the Lodgepole Buttes, at Anarchist Butte, and near Lodgepole post office:

Sections of parts of the Fort Union formation.

T. 22 N., R. 12 E., near Lodgepole post office.

	Ft.	in.
Sandstone, loosely cemented	50	0
Shale, bluish gray	10	0
Lignite	1	6
Shale	3	0
Lignite		6
Sandstone, unconsolidated, gray	8	0
Shale	7	0
Lignite	5	0
Sandstone	20	0
Interval to base of Fort Union	120±	
	225±	

Sec. 36, T. 22 N., R. 8 E.

	Ft.	In.
Sandstone, gray to yellow, friable, with indurated concretions..	10	0
Shale, grayish, weathers yellow; slightly sandy; thin limonite layers; mica flakes	22	0
Shale, brown		10
Shale, gray to brownish	4	0
Shale, brown	1	0
Shale, grayish; weathers yellow; slightly sandy; thin limonite layers; mica flakes	6	6
Shale, brown to black, carbonaceous	2	0
Shale, grayish, slightly sandy; thin limonite layers; mica flakes.	10	9
Shale, brown and gray	3	0
Sandstone, brown, very fine grained, containing clay, with some carbonaceous matter, rather hard		6
Shale, gray to brown	5	6
Shale, brown, very sandy, containing charcoal	2	0
Shale, gray, laminated, sandy, partly carbonaceous	8	0
Shale, brown to dark, fissile	2	4
Shale, gray to yellowish	5	0
Shale, brown to black, fissile	2	0
Shale, gray to yellowish, with thin streaks of limonite; thinly laminated, grading into underlying shale	8	6
Shale,black, brittle, fissile, carbonaceous	1	4
Iron, probably bog iron, containing wood		6
Lignite, dirty		4
Sandstone, brown, bituminous	2+	
Bottom of slope so covered with grass that it is impossible to determine country rock.		
	98	1+

Anarchist Butte, in sec. 34, T. 22 N., R. 9 E.

	Ft.	In.
Sandstone, brown, coarse, forming cap of hill	51	6
Shale, chocolate-colored, with coal smut	1	0
Sandstone, orange to cream-colored, fine grained, with some limonite crusts	20	0
Sandstone, yellow to buff, fine grained, with many limonite layers 4 or 5 inches in thickness; 8 feet above base is a more resistant layer, which forms a shelf in many places	18	0
Shale, chocolate-colored, with some lignite	1	6
Clay, drab	4	0
Quartzite; under surface of layer rather stalactitic	1	6
Clay, lilac-colored	3	0
Shale, black, fissile	1	0
Shale, chocolate-colored, fissile	20	0
Lignite, weathered	1	0
Shale, chocolate-colored	5	0
Lignite, weathered	2	0
Shale, chocolate-colored		6
Sandstone, yellow.		
	130	0

The rocks represented in the interval between the resistant sandstone and limestone of the lower part of the Fort Union and the massive sandstone which caps the Lodgepole Buttes are shaly and carbonaceous, indicating the return to swampy conditions similar to those of the Lance epoch. The beds in this interval are shown in the last two sections given above and are succeeded by a sandstone lens which is represented in the section at Anarchist Butte by the upper four beds. This sandstone is very much like the upper sandstone on the Cave Hills. It is brownish yellow in color and massive in appearance and resists weathering to such an extent as to form an impassable vertical cliff almost continuously around the Lodgpole Buttes. It caps Anarchist Butte and the buttes in Tps. 21 and 22 N., R. 12 E. Its greatest thickness is probably about 100 feet.

A peculiar quartzitic rock occurs at Anarchist Butte and has been traced for many miles in this field as well as in southwestern North Dakota. It is found in place on the top of the Cave Hills, in Lodgepole and Anarchist buttes and several small buttes in T. 22 N., R. 6 E., northwest of Ludlow post office, and in numerous buttes and ridges in Perkins County. The rock on fresh exposure is of a grayish-white to bluish-gray color and is very soft, but on weathering it becomes well indurated and in many places highly polished by wind action. It is composed largely of fine subangular grains of quartz. The rock in places is perforated with impressions of roots and stems, but nothing identifiable was found.

Bowlders of quartzite very similar to those known to be derived from the Fort Union formation and containing impressions of stems and roots are scattered over the surface of much of this field. Two localities are worthy of mention. One is about 2 miles east of Strool, where a ridge about half a mile long and a quarter of a mile wide is formed by angular bowlders as much as 6 feet in diameter, which rest on beds near the middle of the Lance formation. The other locality is south of the Slim Buttes, along Moreau River, where quartzite bowlders as much as 2 feet in diameter cover the surface over an area of several hundred yards and rest on beds very near the base of the Lance formation. The occurrence of angular bowlders 4 to 6 feet in diameter in large numbers and at various altitudes suggest that quartzite probably occurs at other horizons than those in the Fort Union, and, in fact, Todd,[1] in discussing the quartzite, assigns it to the White River formation and gives a section at the south end of the Slim Buttes, including "buhrstone" 1 foot thick, from which, he suggests, the quartzite bowlders may have originated. Darton [2] has noted quartzite, somewhat similar to that described above, in the

[1] Todd, J. E., Geology of South Dakota: South Dakota Geol. Survey Bull. 2, pp. 60-61, 1898.
[2] Dartɩn, N. H., personal communication.

Fox Hills sandstone in Castle Rock, a few miles to the south of this field. It would seem, therefore, that the conditions favorable to the formation of a quartzite existed not only in Fort Union time but also during the earlier epochs and possibly during White River time.

In the part of the Fort Union formation which is exposed in South Dakota there is only one valuable bed of lignite, and that underlies the high ridges north and south of Lodgepole, where it reaches locally a thickness of more than 8 feet. The same bed underlies a number of smaller buttes in adjoining townships, but it is much thinner toward the west.

The line of separation of the Lance from the Fort Union is placed in the eastern part of the field at the top of the beds known to be of marine origin, and in the vicinity of the Cave Hills and Table Mountain at the base of the lowest massive sandstone. It is approximately the line as mapped by Hares [1] during the summers of 1911 and 1912, in Bowman and Billings counties, N. Dak, and by Lloyd in 1912,[2] in Adams and Morton counties, N. Dak.

If there is any unconformity between the Lance and Fort Union in this field it is concealed. Both formations lie so nearly horizontal that it is impossible to detect any difference in the dip and strike.

The only fossils collected from the Fort Union were leaves. These were identified by F. H. Knowlton, as follows:

F 42 (6384). Sec. 34, T. 22 N., R. 9 E., at Anarchist Butte:
- Populus cuneata Newberry.
- Carpites sp.
- Ficus spectabilis? Lesquereux.
- One or two dicotyledons without margin.
- Leguminosites arachioides Lesquereux.
- Sapindus grandifoliolus Ward.
- Populus genatrix? Newberry.

F 49 (6373). SE. ¼ NE. ¼ sec. 4, T. 21 N., R. 12 E.:
- Populus cuneata Newberry.
- Populus amblyrhyncha Ward.
- Platanus sp.
- Ficus? sp.

F 48 (6372). NW. ¼ sec. 3, T. 21 N., R. 12 E.:
- Platanus haydenii Newberry.
- Populus amblyrhyncha Ward.
- Populus cuneata Newberry.

LATER TERTIARY FORMATIONS.

Light-colored clay, marl, sandstone, and conglomerate are exposed in the Slim Buttes, Short Pine Hills, and numerous other isolated hills of northwestern South Dakota. (See Pl. IV.) The lower beds are referred to the White River formation on the basis of the fossils which they contain. The upper beds in the larger areas have been called Arikaree (?) by Darton,[3] and as there is no evidence to the contrary the same nomenclature is used in this report.

[1] Hares, C. J., Lignite in southwestern North Dakota: U. S. Geol. Survey Bull. (in preparation).

[2] Lloyd, E. R., The Cannonball River lignite field, North Dakota: U. S. Geol. Survey Bull. 541, pp. 250-251, pl. 13, 1914.

[3] Darton, N. H., Geology and underground waters of South Dakota: U. S. Geol. Survey Water-Supply Paper 227, p. 31, 1909.

WHITE RIVER FORMATION (OLIGOCENE).

The cross-bedded White River formation, in some places, appears to be truncated and overlain by a heavy-bedded sandstone. Because of the distinct lithologic character of the beds above and below, the later Tertiary rocks are separated into two formations along this contact, the lower part being referred to the White River formation and the upper part to the Arikaree (?). The White River formation, as thus identified, is about 160 feet thick. It consists of light-colored banded clay and sandstone, white grit, and marl and contains many lenses of concretionary siliceous material. The two sections of the White River formation given below show the character of the formation as exposed in this field.

Sections of White River formation.

Slim Buttes, in sec. 1, T. 17 N., R. 7 E.

	Feet.
Clay, flesh-colored, plastic when wet	12
Sandstone, coarse to extremely coarse, calcareous grit; contains much quartz, many fresh feldspar crystals, some clay pebbles	62
Clay, sandy, banded; contains limonite concretions	66
	140

East Short Pine Hills, in sec. 36, T. 17 N., R. 3 W.

Clay, flesh-colored, calcareous; contains seams of chalcedony as much as three-fourths of an inch thick, and thick plates and irregular masses of siliceous concretions with chalcedony streaks; very plastic	60
Like overlying bed, but does not contain the siliceous plates	30
Sandstone, white, unconsolidated; coarse grit with plastic calcareous clay matrix; weathers into fluted forms	66
Unconformity.	
	156

In sec. 36, T. 17 N., R. 1 E., the White River consists of 60 feet of banded white sandy clay, with small limonite concretions. It has the appearance of worked-over Lance material, with the addition of lighter-colored clay.

The White River is cross-bedded on a remarkable scale.[1] The cross-bedding, which is exposed in Reva Gap, was considered by Todd[2] to represent structure, which would necessarily involve the underlying formations. However, the outcrop of a bed of lignite in the southwestern part of T. 18 N., R. 8 E., extends almost continuously along parts of three sides of a projecting point in which the White River formation exhibits an apparent dip of nearly 30°. This lignite bed, which occurs only a few feet below the base of the White River formation, does not dip in accordance with the apparent structure of the White River, but its attitude corresponds with that of the almost flat-lying Ludlow lignitic member of the Lance formation,

[1] Winchester, D. E., Cross-bedding in the White River formation of northwestern South Dakota: Jour. Geology, vol. 21, No. 6, pp. 550-556, 1913.
[2] Todd, J. E., Recent geological work in South Dakota: Am. Geologist, vol. 16, p. 303, 1895.

A. ONE OF THE SMALL BUTTES NORTHEAST OF BISON, S. DAK., SHOWING WHITE RIVER FORMATION RESTING ON LANCE FORMATION.

B. SOUTH FACE OF SLIM BUTTES, SHOWING CLIFF FORMED BY ARIKAREE (?) SANDSTONE.

below. Other good examples of this large scale cross-bedding appear in the Slim Buttes, in sec. 17, T. 18 N., R. 8 E., and in Flat Top Butte, in sec. 30, T. 17 N., R. 9 E. At none of these places does the attitude of the underlying Ludlow lignitic member correspond with the apparent structure exhibited in the White River formation, and therefore the angles exhibited in the White River are interpreted as being due entirely to cross-bedding.

The White River formation lies unconformably on the lower part of the Lance in the Short Pine Hills, on the Ludlow lignitic member in the Slim Buttes, and on the Fort Union in White Butte, T. 22 N., R. 14 E., and in the Cave Hills. The amount of erosion represented by this unconformity is at least 750 feet.

The following fossils were collected from the formation and identified by C. W. Gilmore and J. W. Gidley as White River forms.

F 26. SE. ¼ NE. ¼ sec. 11, T. 16 N., R. 8 E. (from yellow and pink clay near base of White River formation).

Distal end of humerus, probably Merycoidodon culbertsonii.

Fragment of turtle, probably Stylemys nebrascensis.

F 39. Sec. 30, T. 17 N., R. 9 E. (from cross-bedded clay and sandstone at northwest corner of Flat Top Butte).

Merycoidodon culbertsonii Leidy, skull with lower jaws, fragments of lower jaw, limb bones, and foot bones.

Mesohippus? bairdi Leidy, pieces of lower jaws.

Septomeryx? evansi Leidy, skull without teeth and fragments of lower jaw with last lower molar.

Hyracodon nebrascensis Leidy, upper premolar and incisor.

F 27. NE. ¼ SW. ¼ sec. 32, T. 18 N., R. 8 E. (from cross-bedded sandy clay near the base of the White River formation).

Hyracodon nebrascensis Leidy, upper and lower jaws of right side, containing most of molar-premolar series.

F 52. Sec. 3, T. 18 N., R. 14 E. (from clay bed at top of small butte).

Probably Cænopus or Aceratherium, fragments of pelvis.

F 29. Sec. 17, T. 18 N., R. 8 E. (from cross-bedded clay and sandstone near the base of the White River formation).

Various fragments determinable as Merycoidodon culbertsonii Leidy and Hyracodon sp.

Merycoidodon culbertsonii, fragments of skull and teeth.

Hyracodon astragalus.

Septomeryx evansi?

Palæolagus sp.

Mesohippus sp.

F.21. NW. ¼ SW. ¼ sec. 25, T. 19 N., R. 7 E.

Titanotherium.

Cænopus.

Aspideretes.

F 3. SE. ¼ SW. ¼ sec. 36, T. 17 N., R. 1 E.

Merycoidodon.

F 4. SE. ¼ NW. ¼ sec. 17, T. 17 N., R. 2 E.

Cænopus n. sp.

Hoplophoneus?

Septomeryx.

Elotherium mortoni?

Several specimens of a shell reported by William H. Dall to be "probably an undescribed species of Polygyra, allied to the recent Albolabris and having an Eocene aspect," were found in the same beds from which collection F 39 was taken.

ARIKAREE (?) SANDSTONE (MIOCENE?)

The formation here referred to, the Arikaree (?), was called Loup Fork by Todd[1] and Arikaree (?) by Darton.[2] These authors found no fossils in the beds, and consequently based their correlations purely on lithologic grounds.

The formation is composed almost wholly of sandy tuffaceous beds, some of which on weathering show peculiar concretionary forms. Lithologically they resemble the Arikaree in southern South Dakota, which was described and pictured by Darton.[3] The formation in different parts of the Slim Buttes ranges in thickness from 75 to 225 feet. At the base is a greenish-gray, heavily bedded, almost massive sandstone, very fine grained and calcareous. Thin lenses of conglomerate also occur at or near the bottom. The rocks of the formation contain quartz, feldspar, augite, hornblende, epidote, biotite, calcite, and fragments of volcanic glass most of which are angular to subangular. Volcanic material in considerable abundance is revealed in all the slides prepared from these rocks. The Arikaree (?) is the cliff-making formation of the Slim Buttes (see Pl. IV, *B*, p. 32) and of the East and West Short Pine Hills. The following stratigraphic sections show its general character:

Sections of Arikaree (?) sandstone.

Sec. 1, T. 17 N., R. 7 E.

	Ft.	in.
1. Sandstone, greenish gray, rather thin bedded, fine grained, calcareous, and clayey; some thin layers, hard and brittle, show cross-bedding on small scale	68	0
2. Sandstone, similar to No. 1, but more massive and with less clay; some zones composed wholly of concretions, with concentric structure and translucent interior; some of the concretions stalactitic; the surface of this sandstone weathers rough like a complicated carving; it is cross-bedded on a large scale, but not so much so as parts of the White River formation	114	0
3. Conglomerate, pebbles like No. 2, as much as 4 inches in size; the matrix contains waterworn fragments of bones; maximum thickness, 15 feet	7	6
4. Sandstone, thin bedded, much like No. 2	9	0
5. Sandstone and clay, interbedded; surfaces of beds show mud cracks	6	0
Unconformity (?).		
	204	6

[1] Todd, J. E., Recent geological work in South Dakota: Am. Geologist, vol. 16, p. 202, 1895.

[2] Darton, N. H., Geology and underground waters of South Dakota: U. S. Geol. Survey Water-Supply Paper 227, p. 31, 1909.

[3] Darton, N. H., Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 4, pp. 743-747, 1898.

Sec. 36, T. 17 N., R. 8 E.

	Ft.	in.
Top of East Short Pine Hills.		
Sandstone, quartzitic, containing chloritic material; resists erosion to a marked degree; ranges in thickness from 2 to 5 feet..	3	6
Sandstone, fine grained, greenish white, calcareous; forms a steep cliff; weathered surface shows concretionary structure; typical specimens contain angular feldspar, biotite, quartz, epidote, calcite, and fragments of glass, together with chloritic material; called a rhyolite tuff by E. S. Larsen, of the U. S. Geological Survey....................................	140	0
Unconformity (?).		
	143	6

Sec. 36, T. 17 N., R. 1 E.

	Ft.	in.
Top of mesa.		
Sandstone, hard, green, with small veins of chalcedony......	13	0
Sandstone, homogeneous, fairly soft, fine grained, with lavender tinge; conchoidal fracture; some parts rather thin bedded and some massive; some zones minutely cross-bedded; bedding surfaces show mud cracks and ripple marks.............	130	0
Unconformity (?).		
	143	0

No attempt was made in the field to map the White River and Arikaree (?) formations as separate units, although the hachures on Plate I, which represent the cliff faces about the Slim Buttes, West Short Pine Hills, and adjacent buttes closely approximate the limit of the Arikaree (?) sandstone. Where no hachures are shown that formation is absent.

The only fossils found in the Arikaree (?) sandstone were waterworn fragments of bone from a conglomerate near the base of the formation. The specimens were identified by Gidley as follows:

F 25. Sec. 8, T. 16 N., R. 8 E. (from conglomerate near base of Slim Buttes).
Stylemys nebrascensis Leidy.
Hyænodon cruciens Leidy.
Oreodon sp.
Agriochœrus sp.
Age, lower Oligocene, probably equivalent to Titanotherium zone.

F 2. Sec. 36, T. 17 N., R. 1 E.

F 17. SW. ¼ sec. 26, T. 17 N., R. 7 E. (from bed near the base of the formation; the specimens so much waterworn that the bones may have been derived from the underlying White River formation).
Fragments of Merycoidodon.

These collections indicate that the rocks containing them were derived from the White River formation.

QUATERNARY SYSTEM.

The materials of Quaternary age in northwestern South Dakota include terrace deposits along all the principal streams, the deposits on the recent flood plains of the streams, and sand dunes covering

large areas along the South Fork of Grand River in Harding County. No study was made of these deposits and no attempt was made to map them.

STRUCTURE.

The lignite-bearing formations of South Dakota occupy a very shallow structural basin (fig. 3), the main axis of which trends approximately north and lies well toward the eastern edge of the field. The contours in figure 3 show that the beds at the top of the lower part of the Lance formation descend from an altitude of 3,300 feet in T. 22 N., R. 3 E., and 2,700 feet in T. 16 N., R. 15 E., to 2,150 feet in the vicinity of Lemmon. The converging dips indicate that this area lies on the rim of a structural basin the center of which is in North Dakota somewhere north of Lemmon. There are several irregularities in the general structure. Along the western margin of the basin the rocks are most steeply inclined and their dip varies considerably in different areas, but in the central part of the basin they are almost horizontal. South of Grand River, in T. 19 N., R. 8 E., the dip is about 65 feet to the mile (less than 1°) toward the east; at the south end of the Slim Buttes it is approximately 25 feet to the mile toward the north and the strike is about N. 80° W. In the southeastern part of the field, near Chance, the dip is about 12 feet to the mile N. 10° E., whereas at Meadow it is 15 feet to the mile N. 10° W., and at Breckenridge only 7 feet to the mile N. 60° E.

West of the Cave Hills and Slim Buttes the lower strata are brought up in a series of low anticlines. The southern extension of the Glendive anticline of Montana as described by Calvert[1] exposes the top of the Fox Hills sandstone east of Little Missouri River near the North Dakota line and is represented to the southeast by gentle anticlinal structure in the Lance formation. A second fold nearly parallel to the Glendive anticline results in the exposure of the Pierre shale in a small area south of the West Short Pine Hills. The general direction of the two folds is markedly parallel to that of the Black Hills uplift, to the south, and it is probable that they as well as other folds in eastern Montana were produced at the same time and by the same forces.

Very little true faulting has occurred in the field—in fact, the only faults observed are one in the Phillips lignite mine, where the bed is displaced about 3 feet, and several very small ones in the Slim Buttes. There are, however, numerous places where slumping of beds produces effects similar to faulting as well as folding. This slumping is not confined to any particular formation, as rocks of the Lance and the younger formations are much distorted and broken by landslides. The largest landslide in the field (see Pl. III, *B*, p. 10) is in

[1] Calvert, W. R., Geology of certain lignite fields in eastern Montana: U. S. Geol. Survey Bull. 471, p. 201, 1912. (Calvert calls this the Cedar Creek anticline.)

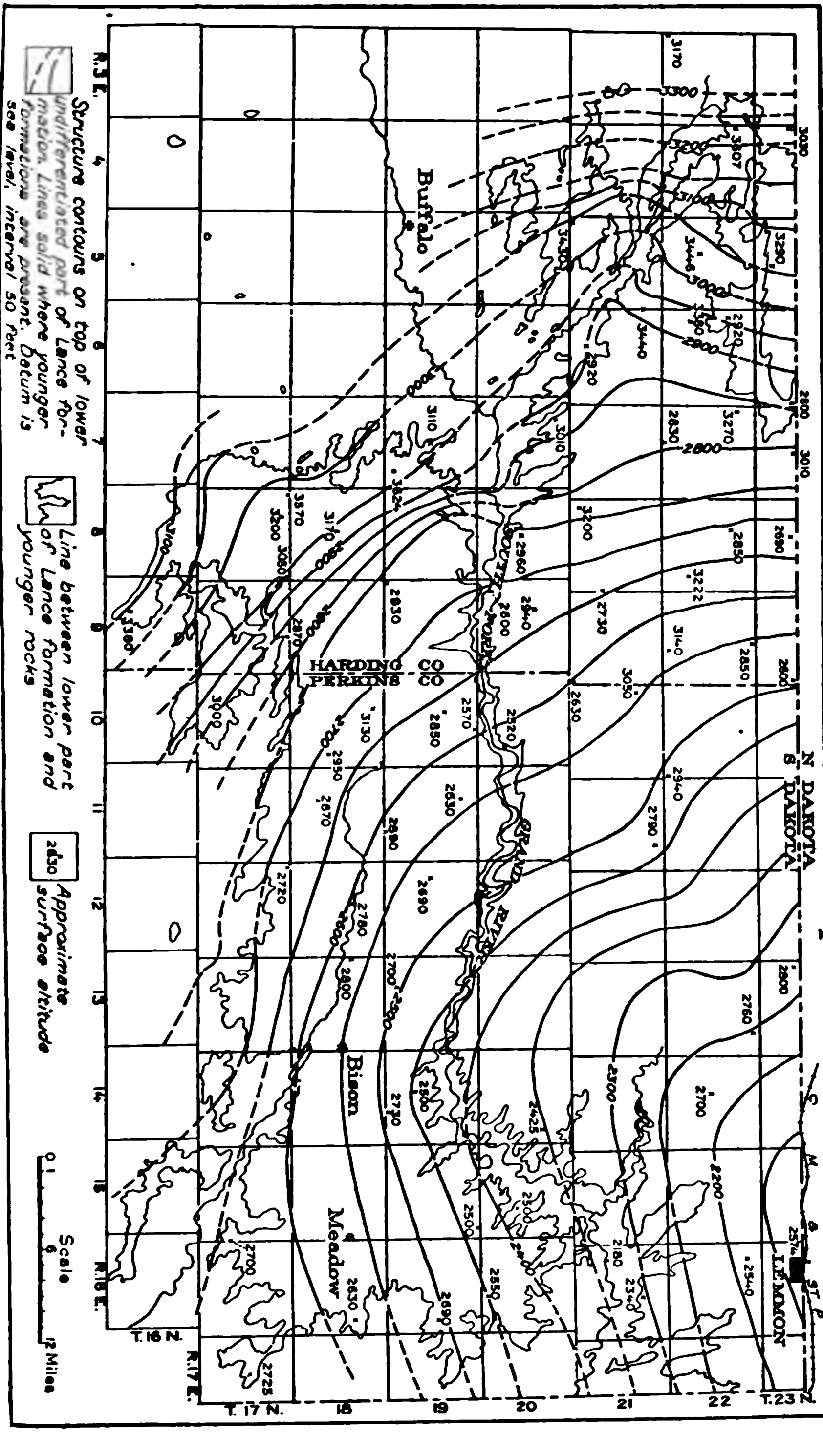

FIGURE 3.—Map showing geologic structure of the lignite field of northwestern South Dakota.

sec. 20, T. 19 N., R. 8 E., where a block of the White River formation about 125 feet thick, 500 feet wide, and half a mile long is exposed in the bottom of a narrow valley. The base of the formation, which is broken and tilted in this slide, is nearly 200 feet lower in altitude than the corresponding horizon in the Slim Buttes, three-fourths of a mile away, and much lower than rocks of the Lance formation which crop out along the sides of the valley. In sec. 27 of the same township an area of Lance rocks, 600 by 2,000 feet, containing a thick bed of lignite, is included in a landslide.

LIGNITE.

LOCATION AND EXTENT.

The lignite field of South Dakota forms the southeastern part of the great lignite field which lies mainly in Montana and North Dakota. From the time of the first exploration of Missouri River by Lewis and Clark in 1804–5 it has been known that thick beds of lignite occur at many places in North Dakota, but their extent has never been accurately determined. The delimitation of the field is complicated by the fact that the thickest and most persistent beds of lignite are contained in the Fort Union formation, and that generally thinner beds occur in the underlying Lance. The extent of the Fort Union in South Dakota was not known prior to the field work on which this report is based, and many writers have assumed that it is present in much of the area supposed to be lignite bearing. The work of 1911 and 1912, however, has shown that the Fort Union formation extends only a short distance into South Dakota and that in the remainder of the field here discussed the lignite beds present are those of the Lance formation. In general the thickness of individual beds, as well as the number of beds, in the Lance decreases toward the southeast, so that although several comparatively thick beds occur in northeastern Harding County, there is but little lignite of commercial value in southeastern Perkins County.

The lignite beds in the lower part of the Lance, although present in a great number of places, are generally thin and of local extent. Most of these lenses are found in the upper 100 feet and almost none of them in the lower 200 feet. One bed in T. 21 N., R. 5 E., and one in T. 21 N., R. 2 E., are thick enough to be of local value.

Lignite has been found in all parts of the field at or near the base of the Ludlow lignitic member of the Lance. The most valuable beds in the field are in this member in the eastern and northeastern parts of Harding County and the western part of Perkins County south of the South Fork of Grand River. The beds in the lower 150 feet of the Ludlow member are in general thin and nonpersistent except around the borders of the Slim Buttes. In the upper 200 feet there are two or three persistent beds, which are most important in

the North and South Cave Hills and Table Mountain and in eastern Harding County north of the South Fork of Grand River and Bull Creek. Lignite beds in this part of the Lance are also well developed in T. 19 N., Rs. 10 and 11 E. These beds, however, are lenticular and the thicknesses are maintained for only short distances. The Cannonball marine member of the Lance was laid down in salt water and does not contain any lignite

The lower part of the Fort Union formation contains practically no lignite in this field, but a thick bed is exposed about 100 feet above the base of the formation. This bed underlies a group of hills north and south of Lodgepole, in Tps. 21 and 22 N., R. 12 E., where it reaches a maximum thickness of 8 feet 10 inches. A few other high buttes in adjoining townships are underlain by the same bed, but it is much thinner both to the west and north.

The rocks overlying the lignite are in many places baked and even fused, the amount of alteration being controlled partly by the quality and thickness of the lignite bed but more by the conditions of burning.

PHYSICAL CHARACTER.

No distinction in character has been observed in this field between the lignite of the Lance and that of the Fort Union formation. Most of the lignite is very dark brown, almost black in color, but the powder is brown. Most of the fresh material has a dull luster and much of it a tough woody texture. Detailed examination of the more woody parts shows some variation in texture, color, and luster. Small lenses of shiny black lignite, ranging in thickness from a thin film to an inch or more, alternate with dark-brown lignite which has not nearly so bright a luster. Both varieties retain in places the fibrous character of the wood from which they were derived. These characteristics are well shown in the lignite from Jones's mine, in sec. 35, T. 19 N., R. 10 E. At Phillips's mine, in sec. 7, T. 17 N., R. 11 E., on a bed near the top of the lower part of the Lance, the lignite is predominantly of the hard black variety and has well-developed cleavage, resembling very closely the subbituminous coal of eastern Wyoming. The analyses of fresh samples from these two mines, however (see table, pp. 42–43), show no appreciable difference in chemical composition. As a rule the lignite in which the woody texture is not well preserved has a dull luster and contains a comparatively high percentage of ash.

On exposure to the air the lignite of this field loses a considerable part of its moisture, shrinks, and soon falls to pieces, a characteristic which makes the shipping of it in open cars to distant markets almost impossible and will prove a serious handicap in its exploitation. The breaking up or checking begins almost immediately when fresh lignite is exposed to the air. The cracks on the surface are in some

places approximately at right angles, so that the small blocks which scale off are roughly cubical in form. In other places the checking is more irregular. In the best lignite the weathered surfaces are black and have a bright vitreous luster, even though in the unweathered condition the lignite is brown and has a dull luster. As the percentage of ash increases, the luster of the weathered surface is duller. The weathering of lignite of different grades is so characteristic that an examination of the weathered face of an exposed section will, in many cases, afford a better conception of the character of the lignite than an examination of the fresh lignite.

CHEMICAL COMPOSITION.

For the sake of uniformity in the comparison of coal and lignite, it is necessary that samples for chemical analysis be free from weathering, but in a region where the greater part of the lignite is taken from strip pits it is difficult to procure fresh material. Eight samples obtained in the northwestern South Dakota field were analyzed at the Pittsburgh laboratory of the Bureau of Mines. Five of these samples were obtained from drift mines and the other three from strip pits. The samples were collected in accordance with the regulations of the United States Geological Survey, which in brief are as follows: From a clean, fresh face a channel is cut perpendicularly from roof to floor, the partings that are thrown out in mining being discarded. The material thus obtained is broken to pass through a ½-inch screen and the sample is reduced by quartering to about 1 quart, which is placed in a galvanized-iron can, sealed, and sent immediately to the laboratory. With the analyses from northwestern South Dakota are included for the sake of comparison analyses of fresh lignite from four producing mines in widely separated parts of North Dakota.

In the following table the analyses are given in four forms, marked A, B, C, and D. Analysis A represents the composition of the sample as it comes from the mine. This form of analysis is not well suited for comparison of one coal or lignite with another, because the amount of moisture in the sample as it comes from the mine is largely a matter of accident, and consequently analyses of different samples of the same coal expressed in this form may vary widely. Analysis B represents the sample after it has been dried at a temperature a little above the normal until its weight becomes constant. This form of analysis is best adapted to the general purposes of comparisons. Analysis C represents the theoretical condition of the lignite after all the moisture has been eliminated. Analysis D represents the lignite after all moisture and ash have been theoretically removed. This is supposed to represent the true lignitic substance, free from the most significant impurities. Forms C and D are obtained from the others by recalculation.

In the analytical work chemists recognize that it is not possible to determine the proximate constituents of coal or lignite with the same degree of accuracy as the ultimate constituents. Therefore the air-drying loss, moisture, volatile matter, fixed carbon, and ash are given to one decimal place only. In the ultimate analyses the ash, sulphur, hydrogen, carbon, nitrogen, and oxygen are given to two decimal places. As calorific determinations to individual units are not reliable, in the column headed "Calories" the heat values are given to the nearest five units, and in the column headed "British thermal units" they are given to the nearest tens, the value of a British thermal unit being about one-half that of a calorie.

Analyses of lignite samples from the northwestern South Dakota and adjoining lignite fields.

[Made by the Geological Survey and the Bureau of Mines, E. E. Somermeier and A. C. Fieldner, chemists in charge.]

Name of mine and location.	Location.				No. on Plate I or II.	Laboratory No.	Air-drying loss.	Form of analysis.	Proximate.				Ultimate.					Heating value.	
	Quarter.	Section.	Township.	Range.					Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calories.	British thermal units.
Phillips mine	SW	7	17 N.	11 E.	879	12488	30.1	A	42.5	a 23.2	25.3	9.00	1.16	7.07	35.22	0.62	46.93	3,310	5,960
								B	17.7	33.2	36.2	12.88	1.66	5.33	50.39	.88	28.86	4,735	8,520
								C		40.4	44.0	15.64	2.02	4.08	61.21	1.08	15.97	5,750	10,350
								D		47.8	52.2		2.39	4.84	72.56	1.28	18.93	6,815	12,270
Knudsen mine	NE	2	17 N.	10 E.	811	12154	19.6	A	34.7	a 26.4	27.6	11.3	1.08						
								B	18.8	32.9	34.4	13.9	1.34						
								C		40.5	42.3	17.2	1.65						
								D		48.8	51.2		1.99						
Jones mine	NW	35	19 N.	10 E.	824	12453	26.0	A	39.2	a 24.7	27.8	8.35	2.22	6.60	38.02	.53	44.28	3,505	6,310
								B	17.8	33.3	37.6	11.28	3.00	5.02	51.38	.71	28.61	4,735	8,520
								C		40.6	45.7	13.72	3.65	3.70	62.49	.87	15.57	5,760	10,370
								D		47.2	52.8		4.23	4.29	72.43	1.01	18.04	6,675	12,020
Mine of Henry Hilton		6	20 N.	5 E.	144	13221	33.0	A	39.8	a 25.3	23.8	11.1	.96					3,045	5,480
								B	10.2	37.8	35.5	16.5	1.44					4,545	8,110
								C		42.0	39.6	18.4	1.59					5,060	9,110
								D		51.6	48.4		1.95					6,200	11,160
M. M. Mendenhall, prospect.		1	17 N.	7 E.	325	13220	34.7	A	41.5	a 24.0	24.3	10.2	.55					3,140	5,650
								B	10.4	36.8	37.3	15.5	.84					4,810	8,650
								C		41.0	41.6	17.4	.94					5,365	9,660
								D		49.6	50.4		1.14					6,495	11,690
Do		1	17 N.	7 E.	326	13222	34.3	A	41.1	a 25.8	24.0	9.1	1.14					2,955	5,320
								B	10.3	39.3	36.5	13.9	1.74					4,495	8,090
								C		43.9	40.7	15.4	1.94					5,015	9,020
								D		51.9	48.1		2.30					5,930	10,680
Newcomb mine	SW	10	20 N.	9 E.	762	15062	26.6	A	34.7	a 27.2	29.0	9.1	.95					3,475	6,250
								B	11.1	37.1	39.4	12.4	1.29					4,735	8,520
								C		41.7	44.4	13.9	1.46					5,325	9,580
								D		48.3	51.7		1.70					6,185	11,140

Nelson mine..........	NW...	29	21 N.	12 E.	937	14354	21.2	A	33.3	a 28.9	27.3	10.5	.70	....	....	....	....	3,868	6,960
								B	15.4	36.7	34.6	13.3	.97	....	....	....	....	4,905	8,830
								C	....	43.4	40.9	15.7	1.14	....	....	....	....	5,795	10,430
								D	....	51.5	48.5	....	1.35	....	....	....	....	6,875	12,380
Nipper & Monroe mine, 3½ miles northeast of Haynes, N. Dak.	NW...	16	129 N.	94 W.	....	14542	14.5	A	32.6	a 30.6	28.5	8.3	1.53	....	....	....	....	4,085	7,360
								B	21.2	35.8	33.3	9.7	1.79	....	....	....	....	4,780	8,600
								C	....	45.4	42.3	12.3	2.27	....	....	....	....	6,070	10,920
								D	....	51.8	48.2	....	2.59	....	....	....	....	6,920	12,460
Mine of Washburn Lignite Coal Co., Wilton, N. Dak.	....	1	142 N.	80 W.	....	1935	32.3	A	40.5	27.1	27.4	5.0	.76	....	....	....	....	3,690	6,640
								B	12.2	39.9	40.4	7.5	1.12	....	....	....	....	5,450	9,810
								C	....	45.5	46.0	8.5	1.28	....	....	....	....	6,205	11,170
								D	....	49.7	50.3	....	1.40	....	....	....	....	6,785	12,210
Mine of Consolidated Coal Co., Lehigh, N. Dak.	....	8	139 N.	95 W.	....	1971	35.6	A	42.1	24.5	25.7	7.7	1.13	....	....	....	....	3,420	6,160
								B	10.0	38.1	40.0	11.9	1.75	....	....	....	....	5,310	9,560
								C	....	42.4	44.4	13.2	1.95	....	....	....	....	5,905	10,630
								D	....	48.8	51.2	....	2.25	....	....	....	....	6,805	12,250
Mine of U. S. Reclamation Service, 3 miles northeast of Williston, N. Dak.	....	7	154 N.	100 W.	....	12533	33.2	A	43.9	a 24.9	25.4	5.8	.49	....	....	....	....	3,300	5,940
								B	16.0	37.2	38.1	8.7	.73	....	....	....	....	4,940	8,890
								C	....	44.3	45.3	10.4	.87	....	....	....	....	5,875	10,580
								D	....	49.5	50.5	....	.97	....	....	....	....	6,555	11,800
Scranton mine of Chas Liddell, Scranton, N. Dak.	SW...	24	131 N.	100 W.	....	14485	22.5	A	34.8	a 31.1	26.0	8.1	.66	....	....	....	....	3,840	6,920
								B	15.9	40.1	33.5	10.5	.85	....	....	....	....	4,960	8,920
								C	....	47.7	39.8	12.5	1.01	....	....	....	....	5,890	10,610
								D	....	54.5	45.5	....	1.15	....	....	....	....	6,730	12,120

a Volatile matter determined by modified method.

Laboratory No. 12488. Sample of lignite bed near top of lower part of Lance formation, in Phillips mine, in sec. 7, T. 17 N., R. 11 E., 5 miles south of Strool, S. Dak.; collected by Dean E. Winchester, July 26, 1911, from fresh face of lignite at end of main entry 150 feet from mine mouth. At the point of sampling the bed is 2 feet 5 inches thick (see No. 879, Pl. XI), all of which was represented in the sample. The sample was unweathered and somewhat wet.

Laboratory No. 12454. Sample of lignite bed at base of Ludlow lignitic member of the Lance formation, from Knudsen mine (see Pl. V, *A*), in sec. 2, T. 17 N., R. 10 E., 5 miles southwest of Strool; collected by Dean E. Winchester, July 21, 1911, from fresh face of coal about 150 feet from mine mouth. The section of the lignite bed at the mine mouth is shown graphically on Plate XI, No. 811. The upper 2 feet 7 inches of lignite was included in the sample. The mine was dry and the lignite unweathered.

Laboratory No. 12453. Sample from a lignite bed in the upper part of the Ludlow lignitic member of the Lance formation, from the Jones mine (see Pl. V, *B*), in sec. 35, T. 19 N., R. 10 E., 6 miles northwest of Strool, S. Dak.; collected by Dean E. Winchester, July 22, 1911, from a fresh face of lignite at the end of the main entry 100 feet from the mine mouth and under about 75 feet of cover. The section at this point is shown on Plate XI, No. 824. The mine was being worked at the time of examination so that the sample for analysis was free from weathering.

Laboratory No. 13221. Sample from a lignite bed near the top of the Ludlow lignitic member of the Lance formation, from the Hilton mine, in sec. 6, T. 20 N., R. 5 E., 11 miles north of Buffalo, S. Dak.; collected by E. M. Parks, October 4, 1911, from fresh face of lignite at end of main entry, 100 feet from mine mouth. Although the bed contains a total of 11 feet 1 inch of lignite only 7 feet 2 inches is mined. A detailed section of the lignite bed at the Hilton mine is shown on Plate VII, No. 144. At the time of sampling the mine had been in operation for about a year.

Laboratory Nos. 13220 and 13222. Samples from lignite beds in Ludlow lignitic member of Lance formation, from the Mendenhall strip pit, in sec. 1, T. 17 N., R. 7 E., S. Dak.; collected by E. M. Parks, August 17, 1911, from faces of beds in an old strip pit after digging back 2 feet in order to get as fresh a sample as possible. Sample No. 13220 represents the lignite of the lower bed; No. 13222 represents that of the upper bed. (See Pl. VII, Nos. 325 and 326.)

Laboratory No. 15062. Sample from Newcomb lignite bed, in the Ludlow lignitic member of the Lance formation, from the Newcomb mine (strip pit), in sec. 10, T. 20 N., R. 9 E., about 28 miles south of Reeder, N. Dak.; collected by J. B. Reeside, jr., October 19, 1912, from face of bed in an open pit; somewhat weathered. A section of the bed at the Newcomb mine is shown graphically on Plate IX, No. 762.

Laboratory No. 14354. Sample from lignite bed in Fort Union formation, from the Nelson mine, in sec. 21, T. 29 N., R. 12 E., 3 miles south of Lodgepole, S. Dak.; collected by E. Russell Lloyd, July 3, 1912, from fresh face of lignite 140 feet from mine mouth, under about 35 feet of cover. The full thickness of the bed was not exposed at this place. The thickness of the part that is being mined is 7 feet (see Pl. X, No. 937), all of which is represented in the sample. Both the roof and floor of the mine at the point of sampling were lignite.

Laboratory No. 14542. Sample from the Haynes lignite bed, in the Fort Union formation, in the Nipper & Monroe mine, 3½ miles northeast of Haynes, N. Dak.; collected by E. Russell Lloyd, July 30, 1912, in entry about 630 feet nearly due east from the mine mouth. The thickness of the bed at this point is about 12 feet, of which the lower 8 feet 3 inches is being mined and was sampled.

Laboratory No. 1935. Sample from a lignite bed in the Fort Union formation, from mine of Washburn Lignite Coal Co., Wilton, McLean County, N. Dak.; collected by M. R. Campbell, August 3, 1905, at 1,750 feet from shaft. The thickness of the bed at this point is 9 feet 6 inches, of which the lower 6 feet 6 inches was sampled.

A. KNUDSEN MINE.

Showing the general character of the strip-pit mines of the region.

B. JONES LIGNITE MINE, NORTH OF STROOL, S. DAK.

Laboratory No. 1971. Sample from a lignite bed in the Fort Union formation, in mine of the Consolidated Coal Co., at Lehigh, Stark County, N. Dak.; collected by M. R. Campbell, August 5, 1905, at 1,900 feet from mine mouth. The thickness of the bed at this point is 6 feet 4 inches, of which the lower 5 feet was sampled.

Laboratory No. 12533. Sample from a lignite bed in the Fort Union formation, from mine of U. S. Reclamation Service 3 miles northeast of Williston, Williams County, N. Dak.; collected by Frank A. Herald, August 16, 1911, at 1,225 feet east from mine mouth. The thickness of the bed at this point is 10 feet 3 inches, of which the lower 8 feet was sampled.

Laboratory No. 14485. Sample from Harmon (?) lignite bed, in the Fort Union formation, from the Scranton mine of Charles Liddell, Scranton, Bowman County, N. Dak.; collected by C. J. Hares, June 30, 1912, from face of east entry, 1,000 feet from mine mouth. The total thickness of the bed is 20 feet 3½ inches. The sample represents 6 feet near the middle of the bed.

In a general way the comparative values of the lignite from different mines and different beds can be obtained from the heating values of the air-dried samples (form B of analysis). This criterion, however, must be modified for lignite in which the loss of moisture on air-drying is comparatively small, as in some of the samples of North Dakota lignite. In the lignite from South Dakota whose analyses are presented above the air-drying loss is fairly uniform. The heating values show that they compare very favorably with lignite that is being mined on a large scale in North Dakota.

All fresh lignite contains a high percentage of moisture, a large part of which is set free on exposure to the air, and a resultant shrinkage takes place, causing the lignite to check or break up into small pieces. There is also a large amount of pyrite or marcasite distributed both along joint planes in large lenses and balls and disseminated in small particles throughout the bed. The larger lenses and balls are thrown out in sampling, so that the sulphur in the bed is greater than is shown by the analysis.

A large part of the northwestern South Dakota lignite field is at present far from a railroad, and therefore the settlers in the region furnish the only market for the lignite. Several small mines have been opened and operated to supply this local trade. Drift mines have been opened in the vicinity of Lodgepole, Strool, and the South Cave Hills.

In nearly all parts of the field the lignite is obtained for local use by stripping off the surface material near the outcrop, and although the labor involved in this process is comparatively great, it seems to be at present the most economical method of mining, for the shale or clay which in most places overlies the lignite is generally not sufficiently compact to serve as a roof.

The lignite is used generally for domestic purposes, but there is a growing demand for it as fuel for the steam plow outfits which are being operated in this part of South Dakota. The low grade and extremely poor stocking qualities of the fuel render it unfit for

shipping in open cars, so that the development, for some years at least, will be limited by the local demand. Experiments made by the Bureau of Mines at Pittsburgh [1] and by the experiment station of the North Dakota School of Mines [2] have proved that the Dakota lignites can be made into briquets at a cost which would place them on the market in favorable competition with high-grade coals. Good producer gas can also be manufactured from lignite, and this may furnish an important market use for the lignite of this field.

AVAILABLE LIGNITE.

In computing the probable amount of lignite available in northwestern South Dakota, only those areas are considered which are known to be underlain by lignite of sufficient thickness to be classified as coal land by the Geological Survey. The lignite of this field has a heating value on air-dry analysis of 8,090 to 8,830 British thermal units,[3] as shown by the chemical analyses (pp. 42–43), and, according to the regulations of the Department of the Interior, a bed of lignite with this heating value must be 2 feet 10 inches thick in order to be considered sufficiently valuable for classification as coal land.

In calculating the tonnage of any lens of lignite its area is determined and the average of the several measurements along the outcrop is assumed to represent the average thickness of the bed. The total content of the lens is determined by multiplying the area in square miles by the average thickness in feet, and this by 1,152,000, the number of short tons of lignite in a square mile of land underlain by a bed 1 foot thick and having a specific gravity of 1.3. By this method it is estimated that there is in Perkins and Harding counties minable lignite amounting to about 1,096,480,000 tons.

DETAILED DESCRIPTIONS BY TOWNSHIPS.

T. 16 N., R. 1 E.

The surface of the northwestern part of T. 16 N., R. 1 E., is a rolling prairie, which slopes gradually upward to the southeast and culminates in a low divide surmounted by a few bare "mud" buttes. The lower part of the Lance formation outcrops throughout most of the township, but the underlying Fox Hills sandstone and Pierre shale are the surface rocks in a small area in the southeast corner. The Fox Hills could not be mapped accurately on account of lack of exposures, but it occupies a narrow belt surrounding the Pierre shale. The strata dip gently to the west. No bed of lignite is exposed in this township.

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[1] Wright, C. L., Briquetting tests of lignite at Pittsburgh, Pa., 1908-9: Bureau of Mines Bull. 14, 1911.

[2] Babcock, E. J., Investigations of lignite coal relative to the production of gas and briquets, North Dakota Univ., Grand Forks, N. Dak.

[3] A British thermal unit is the quantity of heat required to raise the temperature of 1 pound of water 1°, the water being at the temperature of maximum density, 39.1° F.

T. 17 N., R. 1 E.

The western part of T. 17 N., R. 1 E., lies in the low flat valley of Little Missouri River, which flows across the northwest corner. Along the east border is the West Short Pine Hills mesa, which rises abruptly to an elevation of nearly 400 feet above the surrounding country. At the foot of the mesa cliffs is a narrow, deeply dissected area occupied by rocks slumped and washed down from the sides of the mesa. The entire area between the mesa and the river valley is rugged and cut by small streams.

The Lance formation outcrops at the surface throughout the township, except in the West Short Pine Hills, where the White River formation rests unconformably upon the Lance and is in turn overlain by a thick sandstone cap or rim rock that is assigned to the Arikaree (?) sandstone. The strata dip slightly to the west in the central part of the township. In the eastern part there is little opportunity to observe the structure of the Lance formation because of the cover of younger rocks. A general study of the region shows that the axis of a low anticline passes through the township in a nearly north-south direction. No lignite is exposed in the township.

T. 18 N., R. 1 E.

With the exception of a small area of rolling land in the southeastern part, T. 18 N., R. 1 E., lies entirely in the level valley of Little Missouri River, which flows northeastward across the township. This stream, even in the driest years, contains running water, but during the summer months its flow is insufficient to provide much water for irrigation. Camp Crook, in secs. 2 and 3, is the most important town in this part of the field. It has mail and stage connections with Belle Fourche, 70 miles to the south, on the Chicago & Northwestern Railway, and with Bowman, N. Dak., 60 miles to the northeast, on the Chicago, Milwaukee & St. Paul Railway.

The surface rocks belong to the lower part of the Lance formation. The top of the Pierre shale is less than 100 feet below the surface at Camp Crook, as determined by a well. Good rock exposures are rare because of the grass-covered surface. The rock structure is wholly obscured, but a gentle northward-trending anticline is supposed to pass through the township, its axis being near Camp Crook. No bed of lignite is known to outcrop in the township.

T. 19 N., R. 1 E.

The surface in the eastern three-fourths of T. 19 N., R. 1 E., is low and flat, but along the Montana line there is a series of rocky hills covered by a sparse pine growth. The surface rock is somber-colored shale belonging to the lower part of the Lance formation, except that the rocky hills in the western part of the township are

capped by a massive sandstone bed of the Ludlow lignitic member of the Lance. This sandstone shows a distinct westerly dip that increases in amount toward the north until at location 4,[1] in sec. 5, it is more than 10°. The structure is obscured elsewhere in the township, but from data collected in adjacent areas it is inferred that the axis of a gentle north-south anticline passes through the central part of the township.

Two lignite beds 50 to 75 feet apart outcrop in the western part of the township. The lower bed, which occurs at the base of the Ludlow lignitic member of the Lance, has a maximum thickness of 2 feet 7 inches at location 3 in the NE. ¼ sec. 8. The following sections show its character at the exposures in this township:

Sections of lignite beds measured in T. 19 N., R. 1 E.

	Ft.	in.
Location 1. SE. ¼ sec. 30.		
Clay.		
Shale, lignitic, and lignite	1	0
Shale, brown		8
Lignite, dirty		7
Shale, brown		8
Lignite, dirty		10
Total section	3	9
Total lignite	1	5
Location 2. NE. ¼ sec. 30.		
Shale, brown	2	0
Shale, carbonaceous	1	6
Shale, brown	1	8
Lignite	1	7
Shale.		
Total section	6	9
Total lignite	1	7
Location 3. NE. ¼ sec. 8.		
Lignite, good at bottom and dirty at top	2	7
Location 4. NE. ¼ sec. 5.		
Shale.		
Lignite	2	0
Shale.		

The upper bed is represented in this township by 5 feet of interbedded shale and dirty lignite at a single exposure near the center of sec. 8. Elsewhere its outcrop is marked by clinker, except in the ridge in sec. 20, where it is concealed by débris from the overlying beds. Farther west, in Montana, several strip pits have been opened on this bed, and lignite has been mined to supply the local demand in Camp Crook and vicinity.

T. 20 N., R. 1 E.

The surface of the eastern two-thirds of T. 20 N., R. 1 E., is low and flat and is crossed by sluggish streams which are fed by springs from the hills to the west. Small reservoirs have been formed by damming these streams, and the water used to irrigate a part of the flat area. The Ludlow lignitic member of the Lance formation, dipping 8°–10° W., crops out along the western margin of the township in a sandstone-capped ridge. Elsewhere the lower part of the Lance is the surface formation. Although the structure is obscured in the eastern part of the area, it is probable that the rocks there dip

[1] Numbers in text refer to locations on the maps, Plates I and II, and many of them to graphic sections on Plates VI to XI.

eastward, as they do in the township to the north, and that the axis of a gentle north-south anticline crosses the west side of the township. No lignite bed of commercial importance is exposed within the township.

T. 21 N., R. 1 E.

The surface of T. 21 N., R. 1 E., is roughly rolling, with small areas of barren badlands and many rather prominent clinker-capped buttes. The clinker is the result of the burning of lignite and is the most resistant rock in the region. The lower part of the Lance formation forms the surface rock, and the strata dip gently southeastward.

Of the two lignite beds present the lower and more persistent one is thin and of no value. At location 6, in sec. 4, it is represented by 5 feet of brown shale and carbonaceous shale interbedded, and at location 7, in the NE. ¼ sec. 4, the following section was measured:

Section of lignite beds at location 7, in the NE. ¼ sec. 4, T. 21 N., R. 1 E.

	Ft.	in.
Shale.		
Lignite, dirty	1	6
Shale	2	0
Lignite	1	8
Clay, shaly	6	0
Lignite	1	7
Shale.		
Total section	12	9
Total lignite	4	9

The upper and thicker bed has burned, forming high clinker-covered buttes in secs. 8 and 9 and also in the southeastern part of the township, where a small area under thin cover remains unburned. Section 5, Plate VII, was measured in sec. 23, where the bed outcrops near the top of a hill. At this point there are two beds 3 feet 5 inches and 1 foot 9 inches thick, separated by 2 feet 10 inches of shale.

T. 22 N., R. 1 E.

The surface of T. 22 N., R. 1 E., is rolling prairie interrupted by small areas of barren badlands and many prominent clinker-capped buttes. The northwest half drains into Big Boxelder Creek and the remainder directly into Little Missouri River. All the strata which outcrop in the township belong to the lower part of the Lance formation. There are three beds of lignite, the two upper being the same as those which outcrop in T. 21 N., R. 1 E. The lowest was measured only at location 8, in the SW. ¼ sec. 24, where it is 1 foot thick. The middle bed, which corresponds to the lower bed in T. 21 N., R. 1 E., is burned in most of the area, but is preserved under cover in secs. 9, 10, 11, 15, 33, 34, and 35. A section measured in the SE. ¼

sec. 9 (No. 8A, Pl. VII) shows the bed to contain 3 feet 4 inches of dirty lignite. The upper bed is entirely burned, but its former position is shown by the abundant clinker on the buttes in secs. 10, 11, and 15.

T. 23 N., R. 1 E.

Big Boxelder Creek, which drains a large area in Montana, meanders across T. 23 N., R. 1 E., in a broad valley. High cut banks border the creek in many places, but in other parts of the township the land is rolling and rock exposures are confined to a few small areas of badland. The strata of the Lance formation which constitute the surface rocks of the township appear to be horizontal, or to dip almost imperceptibly eastward, except along the west margin, where there is a distinct westerly dip. This dip may be a part of the same structural feature as that which appears in the townships to the south.

A few thin beds of lignite are scattered throughout the Lance but are too thin to be of value in this township.

T. 16 N., R. 2 E.

The surface in the southern part of T. 16 N., R. 2 E., is rolling, but farther north there is an abrupt rise to the level-topped West Short Pine Hills mesa, which occupies the north-central part. Several low ridges slope gently away from the mesa.

The Pierre shale crops out in a rolling plain in the southwest corner and is surrounded by a belt of sandy slopes weathered from the Fox Hills sandstone. The Lance formation, which overlies the Fox Hills and weathers into sandy, rolling prairie, with small patches of badland, is in the Short Pine Hills overlain unconformably by the White River formation. The thick-bedded Arikaree (?) sandstone, which protects the soft White River formation from erosion, is the cap rock of the mesa.

No bed of lignite outcrops in the township, but a bed of hard black bituminous clay exposed in sec. 23 was once mistaken for coal, and an entry was driven on it several feet into the hill.

T. 17 N., R. 2 E.

The small town of Harding lies in sec. 35, T. 17 N., R. 2 E., in a beautiful, gently rolling valley, which Gen. Custer named Pleasant Valley. The best farming land of this part of the field is in this valley, between the two Short Pine Hills mesas. To the southwest the western mesa rises about 400 feet above the general level of the surrounding prairie. The cliff that bounds the mesa on all sides is composed of the Arikaree (?) sandstone, perhaps 50 feet thick, and the slopes below it of the flesh-colored clay and conglomeratic white sandstone of the White River formation. The lower part of the Lance formation outcrops at the foot of the mesa and forms the sur-

face rock of most of the township. It weathers to a sandy soil. The strata are either level or dip very gently to the northeast.

A few lenses of lignite were observed in the Lance formation in this township, but none are of sufficient thickness to warrant mapping.

T. 18 N., R. 2 E.

The divide between the drainage of Little Missouri River and that of the South Fork of Grand River crosses the northeast corner of T. 18 N., R. 2 E. West of the divide the land slopes gently to Valley Creek, but on the east there is an area of pronounced badlands. Strata of the Lance formation constitute the surface and contain several beds of sandstone but no important bed of lignite. The strata dip very gently to the northeast.

T. 19 N., R. 2 E.

In T. 19 N., R. 2 E., the land is low and flat immediately adjacent to Little Missouri River, which flows along the west line of the township, but to the east the surface rises in gentle undulations to the divide between Little Missouri and Grand rivers. The rugged badlands which characterize the east side of this divide are in marked contrast with the rolling topography on the west. Strata of the lower part of the Lance formation outcrop throughout the area, but the rock structure is almost entirely obscured by a heavy mantle of soil.

A few thin lenses of lignite occur in the lower half of the Lance formation. The most extensive bed is exposed in a badland scarp in sec. 26, where the lignite is burned for almost half a mile along the outcrop, so that only a single section is exposed.

Section of lignite bed at location 9, in sec. 26, T. 19 N., R. 2 E.

	Ft.	In.
Shale, sandy.		
Lignite, dirty		3
Lignite	2	0
Clay.		
	2	3

T. 20 N., R. 2 E.

West of Little Missouri River the surface of T. 20 N., R. 2 E., is low and level, but to the east it is rolling, with a few rocky points on the divides. The Lance, the only formation that outcrops in the township, is composed largely of soft clayey shale but contains a few lenticular beds of sandstone, much carbonaceous shale, and a few thin lenses of lignite. Throughout a large part of the township the rock structure is obscured by the mantle of soil and grass, but in the northeastern part the beds dip noticeably to the west and northwest, although the degree of dip is in most places small.

The lowest lignite bed is exposed in a cut bank of the river in sec. 4, where sections 14 and 15 of Plate VII were measured. The bed is

covered by alluvium, and as it does not outcrop elsewhere it is presumed to be a local lens, such as are common in the Lance formation. In the C Y mine (location 14) an open pit worked in the winter to supply ranchers near by with fuel, the bed is 3 feet 4 inches thick and has a thin shale parting near the middle. At location 15 the bed is more than 3 feet 8 inches thick. Several beds occur above this in sec. 10, as is shown by section 12 (Plate VII). The outcrops of the highest and the lowest beds were mapped as far as they could be traced. The uppermost bed at this point contains 3 feet 7 inches of dirty lignite. The lowest is being mined and contains good woody lignite 2 feet 3 inches thick. The same bed is mined at location 13, in sec. 10, where the following section was measured:

Section of lignite bed at location 13, in sec. 10, T. 20 N., R. 2 E.

	Ft.	in.
Shale and lignite interbedded	1	8
Lignite, dirty		11
Lignite	1	7
Clay.		
Total section	4	2
Total lignite	2	6

At location 10, in the SE. ¼ sec. 14, two beds are exposed. The upper one, which is 2 feet 8 inches thick, is correlated with the upper bed at location 12 and is too dirty to be of value; the lower one is only 1 foot 4 inches thick. At location 16, in sec. 3, the lower bed is 1 foot 4 inches thick, but farther north it is not exposed. At location 11, in the NE. ¼ sec. 13, a strip pit has been opened on a bed that shows the following section:

Section of lignite bed at location 11, in the NE. ¼ sec. 13, T. 20 N., R. 2 E.

	Ft.	in.
Shale, carbonaceous, with thin streaks of lignite	1	6
Shale		7
Shale, carbonaceous, with thin streaks of lignite	1	10
Lignite, extremely dirty	1	0
Lignite, fair	1	8
Clay.		
Total section	6	7
Total lignite	2	8

T. 21 N., R. 2 E.

Little Missouri River, which has a narrow flood plain and several high cut banks, meanders across the middle of T. 21 N., R. 2 E., from south to north. The rest of the township is hilly and locally dissected into badlands, with clinker-capped buttes as minor but striking features. Willet post office, on the stage route from Camp Crook to Bowman, is in sec. 4. All the outcropping rocks belong to

the Lance formation, which is made up of somber-colored clay, sandstone lenses, and soft shale, with numerous beds of carbonaceous shale and thin lenses of lignite. The strata are nearly horizontal in most of the township, but in secs. 8, 9, and 10 they dip locally 4° W.

At location 19 three thin lenses of lignite appear in a cut bank of the river. Only the middle and thickest one is shown on Plate VII. Above this group is a bed which is thicker and more persistent than most lignite beds in the lower part of the Lance formation. At location 17, in sec. 36, it is represented by 2 feet of dirty lignite; at location 39, in sec. 30 of the township to the east, the bed is 3 feet 10 inches thick. (See Pl. VII.) At location 18, in sec. 23, the bed occupies a small area near the top of a high butte and is 4 feet thick. In sec. 14 the bed is burned over a considerable area. At location 40, in sec. 18 of the township to the east, the bed is 4 feet 7 inches thick, and at location 21, in sec. 12, it is represented by 3 feet of carbonaceous shale, with no lignite. Section 20, Plate VII, represents strata exposed on the side of Lola Butte, including this bed and other thin beds above it. At location 22 the bed is 4 feet 3 inches thick, but at location 23, in sec. 3, it is composed of only 2 feet 11 inches of dirty lignite at the top, separated by 1 foot 6 inches of shale from 1 foot of good lignite. West of the river, in sec. 5, the same bed is represented by section 25, Plate VII. No exposures were found in the vicinity of sec. 18, but, to judge from the thickness at location 25 and the small amount of baking caused by the burning of the bed farther south, it is probably too thin to be of value. The same bed is also exposed at several places in the township to the north, but it is thin and unimportant. In the northwestern part of the township a few high buttes are capped by a heavy bed of clinker formed by a burned lignite bed which occurs at a higher horizon. At location 26, in sec. 5, a bed which may correspond to one of the lower beds contains several thin benches of lignite, with a total thickness of 1 foot 10 inches.

T. 22 N., R. 2 E.

Little Missouri River flows northward across the western part of T. 22 N., R. 2 E. Except in the narrow valley of this stream the surface is rolling and grass-covered, with small areas of sandy flats in the northeastern part. The lower part of the Lance formation outcrops throughout the township, except in sec. 1, where a small area of Fox Hills sandstone is exposed. The Lance is mostly sandy and contains one bed of lignite. The rocks dip gently westward, except for a local southeast dip in sec. 25.

The thick lignite bed which outcrops in the township to the south is exposed at location 24, near the southwest corner of sec. 36, where it is but a few inches thick, and at location 31, in the southeast corner of sec. 25, where it contains only 1 foot of lignite. A small

area west of the river is underlain by the same bed, which is here much thicker (3 feet to 5 feet 9 inches), as shown by sections 28, 29, and 30, Plate VII.

T. 23 N., R. 2 E.

T. 23 N., R. 2 E., drains into Little Missouri River, which meanders northward across the west side of the township. Within the meanders are sandy alluvial flats, and the valley is bordered by barren hilly areas. In the eastern part there is a low and rather smooth area underlain by the Fox Hills sandstone and fringed hills characteristic of the Lance formation. Only the very top—perhaps 20 feet—of the Fox Hills sandstone is exposed, and the area covered by it is along the axis of the Glendive anticline, which extends northwest to Glendive, Mont.

Only one section of lignite was measured, in the west bank of the river at location 32, in sec. 19, At this place the bed is 10 inches thick.

T. 16 N., R. 3 E.

The East Short Pine Hills mesa, which occupies a considerable area in the northeastern part of T. 16 N., R. 3 E., rises abruptly to an elevation nearly 500 feet above the surrounding prairie and forms one of the prominent landmarks of this part of the field. The top of the mesa is grass covered and its sides are clothed by an abundant growth of small pine trees, from which is derived the name Short Pine Hills. Away from the mesa the surface of the township is undulating and grass-covered, except in a narrow area about the edge of the mesa, where rocks slumped from the cliff have been dissected by recent erosion into intricate badland forms.

The soft somber-colored sandy shale of the lower part of the Lance formation forms the surface of the township, except in the Short Pine Hills, where it is overlain unconformably by the White River and Arikaree (?) formations. The White River is composed of soft greenish and gray marl and sandstone about 100 feet thick and contains numerous fossil bones. The Arikaree (?), which forms the cap rock of the mesa, consists of greenish-gray sandstone with some conglomerate, at least 75 feet thick.

The rocks exposed in this township do not contain important beds of lignite anywhere within its limits.

T. 17 N., R. 3 E.

The East Short Pine Hills, which rise nearly 500 feet above the surrounding area, occupy the southeast corner of T. 17 N., R. 3 E., and are surrounded by a mass of rocks slumped from the edge of the mesa. The divide between the eastward drainage of the South Fork of Grand River and the northward drainage of Little Missouri River extends northward from the Short Pine Hills for 3 miles and

then northwestward. The crest of the divide is a sharp line between areas showing topography of two different types. On the west is an undulating prairie; on the east is a strip of almost impassable badlands locally known as the Jump-off, with sharp ridges, deep gullies, and isolated buttes.

The Arikaree (?) sandstone caps the Short Pine Hills mesa and in places forms an impassable cliff more than 100 feet high. Below this sandstone the soft rocks of the White River formation are exposed in the steep slopes of the hills. A remnant of the White River formation occupies a small area in secs. 13 and 24. The surface rocks of the remainder of the township belong to the lower part of the Lance formation, which in this area contains numerous carbonaceous beds in addition to the usual somber-colored clay and friable sandstone. The strata dip gently to the northeast.

Several thin beds of lignite outcrop in the badlands east of the divide, but only one attains sufficient thickness to warrant mapping. At location 33, in the SE. ¼ sec. 13, 1 foot of lignite is exposed. The same bed at location 34, less than three-quarters of a mile to the north, contains 2 feet of lignite. Except at these two localities, however, the bed is not known.

T. 18 N., R. 3 E.

The divide between the South Fork of Grand River and Little Missouri River crosses the southwest corner of T. 18 N., R. 3 E. To the west the land is rolling and grass covered, but to the east, for 2 or 3 miles, the area is deeply dissected into pronounced badlands, locally known as the Jump-off. The Lance formation, composed of somber-colored sandy clay with scattered ferruginous sandstone concretion-like masses, outcrops throughout the whole township, and the strata dip gently northeastward. No lignite bed of importance is exposed in the township.

T. 19 N., R. 3 E.

The Jump-off, with its deeply dissected badlands, continues northward through T. 19 N., R. 3 E., and occupies the eastern three-fourths of it, but west of the badlands the grass-covered surface slopes gradually toward Little Missouri River. A few high points on the divide are capped by a light-yellow friable sandstone belonging in the Ludlow lignitic member of the Lance formation. An interesting slump of rocks of the White River formation is to be seen in sec. 17, partly on top of the divide and partly in a gully to the east. The age of the rocks involved in the slump is proved not only by their color and composition but also by the fossils they contain. Their presence in this isolated area, together with other masses in place on the Short Pine Hills, Slim Buttes, and elsewhere, indicates that the White River formation once covered a large part of the field. The

beds of the Lance formation dip gently to the northeast. The positions of the outcrops of three small lenses of lignite are shown on Plate I (in pocket). The lowest, at location 36, in sec. 9, is 1 foot 9 inches thick, but its horizontal extent is not great. Just below the base of the Ludlow lignitic member of the Lance is a more persistent bed, exposed in secs. 8, 9, 19, 20, and 30. At location 35, in sec. 19, this bed is represented by 3 feet 2 inches of carbonaceous shale with thin streaks of lignite. At location 37, in the NW. ¼ sec. 9, there is 1 foot 8 inches of good woody lignite at this horizon. Several lignite beds having thicknesses of less than 1 foot 8 inches are exposed in the badlands but are not of sufficient importance to show on the map.

T. 20 N., R. 3 E.

The surface of T. 20 N., R. 3 E. is rolling prairie, but the eastern third is interrupted by badlands. The surface rocks of the township belongs to the Lance formation and dip gently northeastward.

Lenses of lignite, mostly less than a foot thick, are found at several places, but none worthy of mapping was noticed in this area. Along Gallup Creek, in sec. 20, a bed of lignitic shale with streaks of lignite has burned to form a thin clinker. On the line between secs. 27 and 28 is a prominent butte capped with clinker from a bed which is not under cover in this township, but probably corresponds to the bed exposed at locations 35 and 37, in the township to the south.

T. 21 N., R. 3 E.

The surface in the western and northeastern parts of T. 21 N., R. 3 E. is mostly gently undulating and grass covered, but small clinker-capped buttes rising here and there form conspicuous landmarks. In the southeastern part of the township the surface is rather rough. The higher portions of the divide are capped by the Ludlow lignitic member of the Lance formation, and the lower part of the Lance is the surface rock over the rest of the township. The strata are nearly level along the west side and dip gently eastward in the eastern half.

Lignite is exposed at several places in the township and has been mined on a small scale at three localities. The lower bed, which contains the best lignite, crops out in the two deepest valleys crossing the west township line. The lignite has been mined for local use at two places, and secs. 39 and 40 (Pl. VII), show it to be of good quality and thickness at each place. The main outcrop of this bed is in the township to the west (T. 21 N., R. 2 E.), and the description of that township gives more information concerning it. A bed of woody lignite 1 foot 3 inches thick outcrops at location 38, in sec. 35, on the east side of the divide, and may be the same bed. By stripping off the overburden a few loads of fuel have been mined for local use at this place. A lignite bed is exposed in several places at the base of the Ludlow lignitic member of the Lance formation. The bed has

burned in secs. 3, 10, 11, 18, and 19, and its former extent is indicated by several clinker-capped buttes. At location 41, in sec. 14, it is represented by 2 feet of dirty lignite.

T. 22 N., R. 3 E.

The rolling and grass-covered surface of the southern part of T. 22 N., R. 3 E., is interrupted in sec. 33 by a small area of badlands. The central and northwestern parts are characterized by sand dunes, open flats, small playas, and a few bare "mud" buttes. In the northeastern part, which is higher, several clinker-capped buttes stand out in marked contrast to the surrounding plains. A spur of Table Mountain extends from the east into sec. 12.

The Fox Hills sandstone, which forms the surface rock in a small area in secs. 5, 6, 7, and 8, is the oldest formation exposed in the township. Peculiar sandy flats and sand dunes are the result of its disintegration. Overlying the Fox Hills, and apparently conformable with it, is the Lance formation, which is composed of somber-colored shale with a few lenticular beds of yellow sandstone and lignite. The upper part of the Lance (Ludlow lignitic member) is more sandy and contains numerous lignite beds of varying thickness and extent. A small thickness of the upper member remains in the higher buttes and ridges.

Although there are a very few exposures from which to judge the geologic structure, such data as are at hand point to the conclusion that the Glendive anticline described by Calvert[1] is represented here by very low dips in a southwest direction.

Near the base of the undifferentiated part of the Lance, at location 43, in sec. 8, there is a bed of lignite 1 foot thick. This bed, however, is only a small lens which does not extend over any considerable area. At location 42, in sec. 21, about 100 feet higher in the formation, there is a lens of lignite less than a foot thick. At the base of the Ludlow lignitic member of the Lance there is a variable unimportant lignite, as shown by the following sections, taken at locations 44, 45, and 46:

Sections of lignite bed in T. 22 N., R. 3 E.

Location 44. SW. ¼ sec. 12.

	Ft.	in.
Clay.		
Shale, lignitic		8
Lignite, extremely dirty	1	8
Clay		
Total section	2	4
Total lignite	1	8

Location 46. SW. ¼ sec. 1.

	Ft.	in.
Shale.		
Lignite	1	10
Clay.		

Location 45. NW. ¼ sec. 2.

	Ft.	in.
Clay.		
Lignite		1
Clay		1
Lignite		2
Bone		3
Lignite	1	1
Clay		1
Lignite		4
Clay.		
Total section	2	1
Total lignite	1	8

[1] Calvert, W. R., Geology of certain lignite fields in eastern Montana: U. S. Geol. Survey Bull. 471, p. 201, 1912.

A still higher and more valuable bed is present in the NE. ¼ sec. 12. The bed has been burned in part of the area, and its outcrop is concealed elsewhere by talus from the cliff of the mesa just east of the township. To judge from the character of the fusion produced by the burning, it is probable that this bed is more than 3 feet thick. A clinker bed which caps several high buttes in secs. 1, 11, and 12, is probably due to the burning of this bed.

T. 23 N., R. 3 E.

The surface of T. 23 N., R. 3 E., is similar to that of surrounding areas. The Lance is the surface formation of the township, except in the southwest corner, where a small area of the underlying Fox Hills sandstone is exposed. The rocks dip gently to the east, in accordance with the general anticlinal structure which is described in the discussion of T. 23 N., R. 2 E.

Along a badland scarp in sec. 30 a thin lens of lignite, showing the following section, is exposed in the lower part of the Lance:

Section of lignite bed at location 47, in the NE. ¼ sec. 30, T. 23 N., R. 3 E.

	Ft.	in.
Clay, gray.		
Bone, with thin lenses of lignite		11
Lignite, with shiny luster		10
Clay		4
Lignite		1
Clay		1
Lignite		4
Clay.		
Total section	2	7
Total lignite	1	3

At the base of the Ludlow lignitic member of the Lance is a variable bed of lignite, which has burned along its outcrop in secs. 21 and 22. In the SW. ¼ sec. 22 the following section is exposed:

Section of lignite beds at location 48, in the SW. ¼ sec. 22, T. 23 N., R. 3 E.

	Ft.	in.
Shale, brown.		
Shale, carbonaceous, with thin streaks of lignite	2	6
Clay		5
Shale, carbonaceous		4
Lignite		10
Clay	15	0
Shale, lignitic		4
Lignite		11
Clay.		
Total section	20	4
Total lignite	1	9

The lower bed of lignite represents the base of the lignitic member of the Lance.

T. 16 N., R. 4 E.

The eastern and southern parts of T. 16 N., R. 4 E., are in most places rolling and grass covered, but a few high rocky points rise above the general level of the prairie and form conspicuous landmarks. The spur from the East Short Pine Hills in sec. 7 and an outlying butte in sec. 8 are the most prominent points. Between this butte and the mesa to the west is an area of rough badlands.

The Lance, which is the surface formation of most of the township, is composed largely of somber-colored sandy shale with lenticular beds of sandstone and in places thin beds of lignite. This formation is succeeded on the slopes of the mesa and butte by clay and marl of the White River formation, and these are in turn overlain by the Arikaree (?) sandstone, which forms the prominent cliff. The strata dip slightly northeast. In this township no lignite of value is exposed.

T. 17 N., R. 4 E.

The Jump-off, which in T. 17 N., R. 4 E., marks the north side of the divide between Moreau River and the South Fork of Grand River, extends across the southern part of the township. At many places along the northeast side of the divide there is a precipitous scarp with steep ridges and bare "mud" buttes carved from the soft shale of the lower part of the Lance formation. In the northeastern part of the township the land is rolling and grass covered.

The lower undifferentiated part of the Lance formation constitutes the surface rock of the entire township, but the structure is almost wholly obscured by the sand and soil. No lignite of sufficient thickness to warrant mapping is exposed, but thin beds are present at several places in the badlands.

TPS. 18 AND 19 N., R. 4 E.

The surface of Tps. 18 and 19 N., R. 4 E., is characterized by low grass-covered hills and sandy flats sloping gradually toward the South Fork of Grand River, which flows through the southern part of T. 19 N. and drains the entire area. Several "mud" buttes rise as prominent landmarks above the surrounding flat and present a striking contrast to the general rolling topography of the region. A few small areas of badlands are present in the northern part of T. 19 N. and in the extreme southwestern part of T. 18 N.

The soil, which is the result of the disintegration of soft sandy shale and sandstone of the lower part of the Lance formation, is adapted to agriculture, as is shown by the large number of prosperous settlers who live in the area. That the rocks dip gently to the southeast is assumed from the general structure of the region and from a few isolated exposures in the township. No bed of lignite thick enough to warrant mapping is exposed, but there are thin beds at a number of places in the badlands.

T. 20 N., R. 4 E.

Several high, steep-sided buttes along the divide south of Jones Creek in T. 20 N., R. 4 E., and the township to the east stand out above the general rolling grass-covered surface as the most prominent topographic features of the area. The bright-red clinker which caps these buttes and which is the result of the burning of a thick lignite bed is very conspicuous and forms the most resistant member of the rock series in this part of the field. Jones Creek, one of the few perennial streams of the region, drains a large part of the township and occupies a comparatively narrow valley through which it flows in intrenched meanders.

The Lance formation outcrops through the entire area. The lower part is composed largely of soft somber-colored shale and clay, in which occur numerous hard, concretion-like masses of sand. The formation contains numerous fossil remains of such animals as Triceratops, Trachodon, Champsosaurus, and Aspideretes, the bones of which appear scattered over the barren surface at a number of localities. Along the divides and higher areas of the townships the Ludlow lignitic member of the Lance is exposed in considerable thickness and contains beds of lignite of more or less value. The clinker caused by the burning of one of these lignite beds forms the cap rock of several prominent buttes in the central part of the township. A section of the rocks exposed in this part of the field is given on pages 20–21.

At the base of the Ludlow lignitic member is a bituminous shale which locally contains thin lenses of lignite. At locations 52 and 53, in sec. 35, there is about 1 foot of lignite, and at location 54, in sec. 26, several feet of dark-brown shale, with a few inches of lignite, occurs at the same horizon. In sec. 16 the following beds are exposed:

Section of lignite bed at location 55, in the SE. ¼ sec. 16, T. 20 N., R. 4 E.

	Ft.	in.
Clay.		
Shale, bituminous	0	2
Lignite	1	11
Shale	1	1
Lignite	1	4
Clay.		
Total section	4	6
Total lignite	3	3

The lignite is of good quality. At location 59, in sec. 5, there is only 1 foot of lignite at this horizon.

Above this there are two other beds of lignite of varying thickness and quality, as well as several bands of carbonaceous shale. Section 51 (Pl. VII) represents both beds, each of which is about 5 feet thick and extremely dirty. Below the lower bed and separated from it by 2 feet 9 inches of shale is a local bed 2 feet 7 inches thick. At loca-

tion 50, a few yards west of location 51, the lower bed is 3 feet thick and much better in quality and has been mined for local use. Sections 56 and 58 (Pl. VII) represent the main lower bed as exposed in two small buttes in secs. 14 and 24. The total thicknesses of the bed at these places are 6 feet and 5 feet 7 inches, respectively. The clinker that caps these buttes is the result of the burning of the upper bed. Along the sides of the butte, in sec. 27, the bedrock is obscured by débris from the overlying rocks and no bed of lignite is exposed, although such a bed may be present.

T. 21 N., R. 4 E.

The land in the valley of Bull Creek in the north half of T. 21 N., R. 4 E., is rolling and grass-covered but rises rather abruptly to the high divide to the south. Beyond the divide the surface slopes gently toward Jones Creek, which flows eastward across the township south of this one. The South Cave Hills (see Pl. III, *A*, p. 10) in the southeastern part of the township, form one of the most prominent topographic features of the field. They rise abruptly 250 to 300 feet above the general level of the plains, and occupy a large area in this and adjacent townships. The massive light-brown or yellowish sandstone, which in places is as much as 80 feet thick, stands out as a sheer cliff at the top of the mesa, and in this township is the only representative of the Fort Union formation. Beneath this sandstone is a succession of sandy shale, sandstone, and lignite beds that are referred to the Ludlow lignitic member of the Lance formation. In this part of northwestern South Dakota the more valuable beds of lignite occur in this member. The lower part of the Lance outcrops in the valleys of Bull Creek and Jones Creek.

Lignite beds of varying thickness, quality, and extent are exposed in this township. The thickest and most extensive bed is in the Ludlow lignitic member and outcrops well up on the side of the South Cave Hills mesa. Its topographic location has probably prevented its exploitation. The only bed from which lignite has been mined is near the top of the lower part of the Lance and outcrops along the valley of Bull Creek.

The exact correlation of the several sections measured in this township is difficult because of the lack of exposures and the variability of the lignite beds. Four valuable beds in the Ludlow member of the Lance are exposed at location 70, in the north face of the South Cave Hills, but at no other place in the township is there so complete a section revealed.

Three sections in secs. 14 and 15 represent the lowest beds exposed. At each of locations 90A and 91, in the NW. ¼ sec. 14, 2 feet of dirty lignite occurs. It is probable that the upper and lower beds at location 80 are the same as those at locations 90A and 91, respectively.

Sections of lignite beds at location 80, in the NE. ¼ sec. 15, T. 21 N., R. 4 E.

	Ft.	in.
Shale and clay.		
Lignite	1	11
Clay, gray	7	0
Shale, brown		6
Lignite	1	4
Clay.		
Total section	10	9
Total lignite	3	3

Above these beds and near the top of the lower part of the Lance formation is a bed which has considerable extent, but is not thick enough to be of much value. Its maximum thickness (4 feet 6 inches) is exposed at location 90, in the NE. ¼ sec. 14, but a short distance to the north, at location 88, the bed is split into three benches by thin shale partings. (See Pl. VII.) Sections measured at locations 78, 79, and 92 are shown graphically on Plate VII, but at other places the bed is thin, as is shown by the following sections:

Sections of lignite bed 4 feet below the top of the lower part of the Lance formation.

Location 73. SW. ¼ sec. 28.

	Ft.	in.
Clay.		
Shale, carbonaceous		8
Lignite	1	2
Shale.		
Total section	1	10
Total lignite	1	2

Location 75. SE. ¼ sec. 21.

	Ft.	in.
Clay, sandy.		
Lignite, poor	1	8
Shale	2	11
Lignite, poor		6
Lignite	1	10
Shale.		
Total section	6	11
Total lignite	4	0

Location 76. SW. ¼ sec. 22.

	Ft.	in.
Clay, sandy.		
Lignite	1	3
Shale, brown		2
Shale, carbonaceous		8
Lignite	1	0
Shale.		
Total section	3	1
Total lignite	2	3

Location 77. SW. ¼ sec. 22.

	Ft.	in.
Lignite	1	7

At the base of the Ludlow member of the Lance there is a thin bed which was mapped in secs. 30, 31, and 32, and along the northwest side of the South Cave Hills. It was examined at locations 60, 61, 74, 81, 82, 83, 84, 85, and 89, and all the sections except those at locations 60 and 89 are shown graphically on Plate VII. At location 60, in sec. 32, the bed contains only 6 inches of lignite, and at location 89, in sec. 13, it is represented by nothing but shale.

In the side of the South Cave Hills mesa within a stratigraphic distance of less than 100 feet there are at least four beds of lignite, as shown by section 70 (Pl. VII). The lowest bed is exposed at locations 68, 70, 71, and 72 and ranges in thickness from 9 feet 6 inches at location 72, in the SE. ¼ sec. 25, to 1 foot 2 inches at location 68,

in the SW. ¼ sec. 23. At location 71 it is represented by about 4 feet of weathered lignite. The next higher bed, shown in sections 69, 70, and 86 (Pl. VII), is 15 feet above the lowest bed at location 70 and ranges in thickness from 2 feet 6 inches at location 86 to 5 feet 5 inches at location 69. About 12 feet above this bed is a third bed, represented by secs. 62, 63, 65, 66, 67, 70, and 87, (Pl. VII), which is the only persistently thick bed outcropping in this township. Its thickness ranges from 4 feet 1 inch at location 70 to 8 feet 9 inches at location 66. The highest bed is partly exposed at only one place in this township. (See section 64, Pl. VII.)

T. 22 N., R. 4 E.

Table Mountain, a high mesa with rocky slopes similar to those of the Cave Hills, occupies the northwest corner of T. 22 N., R. 4 E. This mesa and a series of high buttes along the divide to the southeast form prominent landmarks of the region, rising several hundred feet above the surrounding country. Surrounding the mesa is an area of rather elevated rolling grass-covered country where the soil is fertile enough to attract numerous settlers, who can, by dry-farming methods, raise good crops of small grains, potatoes, flax, etc. Most of the area is drained toward the southeast by two small streams that occupy broad, open valleys, but the northeastern part is drained eastward by Crooked Creek. The Fort Union formation is represented in this township by the sandstone that caps Table Mountain and several isolated buttes to the south. Beneath this sandstone there are exposed friable yellow sandstone and sandy shale, containing numerous carbonaceous and lignitic beds. These rocks are referred to the Ludlow lignitic member of the Lance formation. The upper part of the somber-colored shale which constitutes the lower part of the Lance is exposed in the deeper valleys. The rocks dip uniformly to the east at about 45 feet to the mile.

The lowest lignite bed exposed is in the Lance formation at location 93, in sec. 33.

Section of lignite bed at location 93, in the SE. ¼ sec. 33, T. 22, N., R. 4 E.

	Ft.	in.
Sand, yellow.		
Lignite, dirty, variable in thickness		4
Clay	2	0
Lignite	2	2
Clay.		
Total section	4	6
Total lignite	2	6

This bed is only a small lens, but a strip pit has been opened on it and lignite is being mined for local use.

In this township, as in other parts of the field, a thin bed is present in some places at the base of the Ludlow member of the Lance. At

location 94, in the SW. ¼ sec. 34, there is 1 foot 1 inch of good lignite; at location 119, in the NE. ¼ sec. 18, 2 feet; and at location 113, in sec. 13, the bed is thin and badly split up by partings, as is shown by the following section:

Section of lignite bed at location 113, in sec. 13, T. 22 N., R. 4 E.

	Ft.	in.
Shale.		
Lignite		8
Clay		1
Lignite		5
Shale		1½
Clay		3
Lignite		8
Clay.		
Total section	2	2½
Total lignite	1	9

The most persistent and thickest bed exposed in this township is less than 50 feet above the base of the Ludlow member. In several small isolated areas at locations 95, 96, and 97, in secs. 27, 34, and 35, the bed is under a rather thin cover. At location 97 it contains only 2 feet 2 inches of poor lignite, but at the other two locations the bed is more valuable. (See Pl. VII.) In sec. 28 the bed has burned and the resulting clinker caps a large low butte. At locations 98 and 99, in sec. 17, measurements show 4 feet and 4 feet 2 inches of lignite, respectively, and at location 99 a strip pit has been opened and lignite mined for local use. No good exposures were found in secs. 7, 8, or 9, the 1 foot 6 inches of lignite exposed at location 110 probably representing only the upper part of section 99. Sections 103, 104, 105, 106, 107, 108, 111, 123, and 124, on Plate VII, show the character of the bed where exposed in the northern part of the township, the maximum thickness being more than 8 feet at location 105, in sec. 12. Some lignite has been mined from this bed for local use at location 103, in the NE. ¼ sec. 24, and at location 123, in the NE. ¼ sec. 6.

A minor lignite bed above this bed crops out in secs. 5, 17, and 20. At location 120 it contains 2 feet 6 inches of poor lignite, and at location 109 there is 2 feet 9 inches of lignite. At location 102, in the SE. ¼ sec. 17, there is 1 foot 8 inches of lignite, but at location 101, in the NW. ¼ sec. 20, the bed is represented by a few inches of carbonaceous shale.

Still another good bed underlies the higher part of the mesa, where its outcrop is usually covered by débris slumped from the rim rocks above. Several measurements were obtained, however, which are shown by sections 100, 112, 114, 115, 117, 118, 121, and 122, on Plate VII. The bed ranges in thickness from 2 feet 9 inches at location 117, to 6 feet 10 inches at location 114. At locations 118 and 122

small strip pits have been opened from which near-by farmers obtain their supply of fuel.

Below the rim rock at location 116, in sec. 8, a 1-foot 9-inch bed of lignite is exposed, but it is probably not persistent.

T. 23 N., R. 4 E.

The western and northern parts of T. 23 N., R. 4 E., are drained by tributaries of the North Fork of Grand River, and the southeastern part by tributaries of Crooked Creek. Sloping away from the comparatively level upland area in the central part of the township is a rolling, grass-covered country, which on the west is somewhat dissected into badlands. A striking topographic feature in the eastern half of the township consists of the large number of reddish hills capped by baked rocks caused by the burning of the main lignite bed.

The eastern two-thirds of the township is well settled, but the western two tiers of sections are for the most part not suitable for farming, as they are decidedly rough and the soil is rather infertile.

The rocks exposed in the township belong to the Lance formation and have a total thickness of about 250 feet. The upper 150 feet contains thin beds of lignite which, in the main, are of little value and in places merge horizontally into brown carbonaceous shale. This part of the formation is differentiated as the Ludlow lignitic member. The strata are nearly horizontal but have a slight eastward dip of about 40 feet to the mile.

The only good bed of lignite in this township is in the lower part of the Ludlow lignitic member of the Lance formation. Sections were measured on it at locations 124, 125, 126, 128, 129, 130, 131, and 133. The measurements obtained at these points are shown graphically on Plate VI. The thickest section was that measured at location 131, in a strip pit in the northeast corner of sec. 26, where 7 feet 5 inches of lignite is exposed. The bed at that place is separated by 22 feet of shale with some lignite from a lower bed of lignite about 2 feet 6 inches thick. The same bed is worked in small strip pits at locations 130, 125, and 124, in secs. 22, 29, and 32, respectively. At these places the lignite appears to be of rather low grade and impure, being much broken up by thin shale partings with streaks of dirty lignite. This bed is possibly the same as the one at the Durkin mine, in sec. 34, T. 130 N., R. 103 W., N. Dak. In the eastern part of the township the lignite has burned extensively along the outcrop. The maximum thickness of the strata overlying the bed is 75 feet.

Below the main bed are several beds less than 2 feet 6 inches thick. One of these is exposed in secs. 20 and 21, and at location 132, in the NW. ¼ sec. 21, it has a thickness of 2 feet 1 inch. Another minor bed 45 feet above the main bed is exposed at location 127, in the SW. ¼ sec. 21, where it is 2 feet 6 inches thick.

TPS. 16, 17, 18, AND 19 N., R. 5 E.

The area embraced in Tps. 16, 17, 18, and 19 N., R. 5 E., extends from the southern boundary of the field to a point within about 4 miles north of Buffalo, the county seat of Harding County. For the most part the surface is gently undulating and grass-covered, sloping toward the South Fork of Grand River on the north and toward Moreau River on the south. Areas of migrating sand dunes are common in T. 18 N., and badlands carved from the soft sandy shale of the lower part of the Lance formation occur along the divide between the two drainage systems. A few barren "mud" buttes relieve the monotony of the landscape in the southern part of the area. Except in the part of the area north of South Fork of Grand River, the land is largely unsettled and is used for sheep range. The only permanent stream is the South Fork of Grand River, and even that is nearly dry in the summer season.

The shale of the lower part of the Lance formation occupies the surface of the area, and although there are numerous carbonaceous beds in the formation, at only one place is lignite known to be present. A small strip pit at location 134, in sec. 12, T. 17 N., R. 5 E., has been opened on a bed having a thickness of 1 foot 6 inches and has yielded considerable fuel for the ranchers near by. No appreciable structure is evident in this area.

T. 20 N., R. 5 E.

The surface of the two southern tiers of sections in T. 20 N., R. 5 E., is gently rolling, with a high clinker-capped butte in sec. 30 and a flat-topped butte capped by resistant sandstone in sec. 36. The surface of the rest of the township is roughly rolling, except that part occupied by the Cave Hills and the outlying buttes, which rise about 300 feet above the average surface of the plain. The area is, for the most part, too rough and broken for agriculture and is used almost entirely for stock raising.

Shale of the lower part of the Lance formation crops out in the broad valleys but is succeeded on the divides by the soft sandstone and sandy shale of the Ludlow lignitic member of the Lance. The tops of the mesas and buttes are capped by the lowest sandstone of the Fort Union formation. A small remnant of the White River formation occurs on the top of the mesa in sec. 5. The strata dip gently to the northeast.

Four different beds of lignite are present, but the thickest and most extensive is in the Ludlow lignitic member of the Lance. One drift mine and several strip pits have been operated in this township. The largest operation is at the Hilton mine (see section 144, Pl. VII), in sec. 6, where a drift has been driven 120 feet into the hill on a bed showing the following section:

Section of lignite bed in Hilton mine.

	Ft.	in.
Lignite (roof)	1	11
Shale		6
Lignite (sampled for analysis)	2	10
Shale		1
Lignite (sampled for analysis)	4	4
Shale, reported	2	0
Lignite	2	0
Total section	13	8
Total lignite	9	2

The two middle benches, aggregating 7 feet 2 inches of lignite, are mined; but the upper bench is left for roof. A sample of the lignite was taken for analysis (No. 13221, p. 42) and found to contain a large percentage of ash. At location 141, in sec. 20, the following section on the same bed is exposed in a strip pit:

Section of lignite bed at location 141, in the SW. ¼ sec. 20, T. 20 N., R. 5 E.

	Ft.	in.
Clay, gray to brownish.		
Lignite, dirty		4
Shale, brown, and gray clay	5	0
Lignite		6
Clay, gray	1	10
Lignite	1	9
Clay, gray.		
Total section	9	5
Total lignite	2	7

Two small strip mines, at locations 137 and 138, have been opened on a bed in the lower part of the Lance, but owing to the thinness of the bed (1 foot 7 inches and 2 feet 4 inches, respectively) the amount of fuel removed from each place has been small. This bed is exposed also at locations 135 and 139, where it has thicknesses of 1 foot 10 inches and 2 feet, respectively.

The carbonaceous bed that marks the base of the Ludlow member of the Lance was examined at two places. At location 136 it is represented by 20 feet of carbonaceous shale with thin streaks of lignite, and at location 142 there is a bed of dark shale several feet thick but no lignite.

The bed opened at the Hilton mine is exposed at two other places (locations 145 and 146), at neither of which is the lignite thick or clean. The following section was measured:

Section of lignite bed at location 145, in the SW. ¼ sec. 4, T. 20 N., R. 5 E.

	Ft.	in.
Shale, brown.		
Bone, very sandy, purplish, of variable thickness; maximum	3	0
Clay, brown, of variable thickness; maximum	2	0
Lignite, dirty, variable in thickness		8
Shale		4
Lignite	1	6
Shale.		
Total section	7	6
Total lignite	2	2

At location 146, in the NW. ¼ sec. 4, there is only a few inches of lignite in this bed. The lignitic shale at location 143, in sec. 12, is supposed to be at the same horizon. The highest bed outcrops around the butte in secs. 19 and 20, and at location 140 it contains 6 feet 7 inches of impure lignite. Rattlesnake Butte, in sec. 30, is capped by clinker from this bed.

T. 21 N., R. 5 E.

Parts of both the North and South Cave Hills lie in T. 21 N., R. 5 E., the North Cave Hills occupying the northeast corner and the South Cave Hills the southwest corner. Between them are the broad, rolling valleys of Bull Creek and its tributaries Dry and Camel creeks. Bull Creek, one of the few perennial streams of the region, crosses the township from west to east in a broadly meandering course and receives the run-off from the whole area. On both sides of its narrow, steep-sided channel the surface rises in gently rolling, grass-covered slopes to the bases of the mesas.

The Cave Hills mesas cover an area of several square miles and rise several hundred feet above the surrounding country in almost impassable cliffs. In this township several narrow, flat-topped ridges, separated by deep box canyons, extend beyond the main area of the mesas and give the surface a very rugged appearance. A large butte in sec. 18 and two smaller ones in secs. 19 and 20 are capped by the same resistant yellow sandstone as the principal mesas. Below the cap rock of the mesa there is a steep talus slope, on which are large blocks of sandstone, slumped down from the cliff, which make the area almost impassable.

The Lance formation outcrops in the valleys, but the cap rock of the mesas and the prominent buttes belongs to the Fort Union formation. There is a small area of White River formation in secs. 31 and 32. In most places the beds dip northeastward about 50 feet to the mile, but in sec. 24 and in a narrow area to the northwest they dip toward the southwest. The general northeasterly dip apparently prevails in the northeast corner of the township.

Several lignite beds, varying in thickness and quality, outcrop in this township. Because of the variability of the beds and the lack of exposures the exact correlation of beds between sections is in many places very difficult.

The lowest lignite bed is about 50 or 60 feet below the base of the Ludlow lignitic member of the Lance and is the most extensive bed in the township. (Exposed at locations 147 to 159 and 174, Pl. I.) It is at approximately the same horizon as the lowest exposed bed in T. 20 N., R. 5 E. At location 147, in sec. 36, there is no lignite, the bed being represented by several feet of brown and black shale. To the west the bed thickens rapidly, showing 3 feet 9 inches of good lignite at location 148, in sec. 34, where it is mined for local use. (See Pl. VII.)

Up Dry Creek, west of locations 149 and 150, there are no exposures of lignite, but a very small amount of clinker in the northeastern part of sec. 21 probably represents the same bed and it is assumed that the bed is thin or absent west of the center of sec. 21. Along the south side of Bull Creek the bed ranges in thickness from a few inches at location 151 to 1 foot 3 inches at location 152, 2 feet 10 inches at location 153, and 6 feet 5 inches at location 155. North of Bull Creek, at location 157, in sec. 14, there is a small strip pit on the bed, which is here 5 feet 4 inches thick. At location 158 the same bed has a total thickness of 5 feet 11 inches but is dirty and split into three benches. At location 159 it contains only 3 feet 6 inches of dirty lignite. To the northwest, beyond location 157, the outcrop is concealed, but at location 174, in sec. 4, a bed more than 4 feet 9 inches thick is supposed to represent the same horizon. The outcrop of this bed of lignite is particularly well situated for opening extensive strip pits, the most economical method of mining at the present time.

Lignite at the base of the Ludlow lignitic member of the Lance is exposed at two places in the township, where the sections are as follows:

Sections of lignite bed at the base of the Ludlow lignitic member of the Lance formation in T. 21 N., R. 5 E.

Location 183. NW. ¼ sec. 19.	Ft.	in.
Sand.		
Lignite, dirty	1	5
Lignite	2	0
Clay.		
Total lignite	3	5

Location 184. West side of NE. ¼ sec. 29.	Ft.	in.
Shale, brown to black.		
Lignite	1	4
Lignite, very dirty	1	2
Clay.		
Total lignite	2	6

A small strip pit has been opened at location 183, but little lignite has been mined from it.

In the South Cave Hills four lignite beds of varying thickness and quality are exposed above the base of the Ludlow lignitic member of the Lance. Although there is more than 3 feet of lignite at two or more places the beds are not regular in thickness and mining has been undertaken only at location 185, in sec. 30. Lack of exposures along the outcrops of the beds prevents exact correlation, but the following statement indicates the approximate relation of sections measured in this part of the township:

Relation of lignite beds in southwestern part of T. 21 N., R. 5 E.

	Feet.
Lignite bed shown in sections 179 and 180, Plate VII, and section 178, page 70.	
Interval	50
Lignite bed shown in sections 188, 189, and 190, page 70.	
Interval	25
Lignite bed shown in sections 181, 182, and 185, Plate VII, and sections 186, 188, and 191, page 70.	
Interval	30
Lignite bed shown in section 185, Plate VII, and section 187, page 70.	

T. 20 N., R. 4 E.

Several high, steep-sided buttes along the divide south of Jones Creek in T. 20 N., R. 4 E., and the township to the east stand out above the general rolling grass-covered surface as the most prominent topographic features of the area. The bright-red clinker which caps these buttes and which is the result of the burning of a thick lignite bed is very conspicuous and forms the most resistant member of the rock series in this part of the field. Jones Creek, one of the few perennial streams of the region, drains a large part of the township and occupies a comparatively narrow valley through which it flows in intrenched meanders.

The Lance formation outcrops through the entire area. The lower part is composed largely of soft somber-colored shale and clay, in which occur numerous hard, concretion-like masses of sand. The formation contains numerous fossil remains of such animals as Triceratops, Trachodon, Champsosaurus, and Aspideretes, the bones of which appear scattered over the barren surface at a number of localities. Along the divides and higher areas of the townships the Ludlow lignitic member of the Lance is exposed in considerable thickness and contains beds of lignite of more or less value. The clinker caused by the burning of one of these lignite beds forms the cap rock of several prominent buttes in the central part of the township. A section of the rocks exposed in this part of the field is given on pages 20–21.

At the base of the Ludlow lignitic member is a bituminous shale which locally contains thin lenses of lignite. At locations 52 and 53, in sec. 35, there is about 1 foot of lignite, and at location 54, in sec. 26, several feet of dark-brown shale, with a few inches of lignite, occurs at the same horizon. In sec. 16 the following beds are exposed:

Section of lignite bed at location 55, in the SE. ¼ sec. 16, T. 20 N., R. 4 E.

	Ft.	in.
Clay.		
Shale, bituminous	0	2
Lignite	1	11
Shale	1	1
Lignite	1	4
Clay.		
Total section	4	6
Total lignite	3	3

The lignite is of good quality. At location 59, in sec. 5, there is only 1 foot of lignite at this horizon.

Above this there are two other beds of lignite of varying thickness and quality, as well as several bands of carbonaceous shale. Section 51 (Pl. VII) represents both beds, each of which is about 5 feet thick and extremely dirty. Below the lower bed and separated from it by 2 feet 9 inches of shale is a local bed 2 feet 7 inches thick. At loca-

tion 50, a few yards west of location 51, the lower bed is 3 feet thick and much better in quality and has been mined for local use. Sections 56 and 58 (Pl. VII) represent the main lower bed as exposed in two small buttes in secs. 14 and 24. The total thicknesses of the bed at these places are 6 feet and 5 feet 7 inches, respectively. The clinker that caps these buttes is the result of the burning of the upper bed. Along the sides of the butte, in sec. 27, the bedrock is obscured by débris from the overlying rocks and no bed of lignite is exposed, although such a bed may be present.

T. 21 N., R. 4 E.

The land in the valley of Bull Creek in the north half of T. 21 N., R. 4 E., is rolling and grass-covered but rises rather abruptly to the high divide to the south. Beyond the divide the surface slopes gently toward Jones Creek, which flows eastward across the township south of this one. The South Cave Hills (see Pl. III, *A*, p. 10) in the southeastern part of the township, form one of the most prominent topographic features of the field. They rise abruptly 250 to 300 feet above the general level of the plains, and occupy a large area in this and adjacent townships. The massive light-brown or yellowish sandstone, which in places is as much as 80 feet thick, stands out as a sheer cliff at the top of the mesa, and in this township is the only representative of the Fort Union formation. Beneath this sandstone is a succession of sandy shale, sandstone, and lignite beds that are referred to the Ludlow lignitic member of the Lance formation. In this part of northwestern South Dakota the more valuable beds of lignite occur in this member. The lower part of the Lance outcrops in the valleys of Bull Creek and Jones Creek.

Lignite beds of varying thickness, quality, and extent are exposed in this township. The thickest and most extensive bed is in the Ludlow lignitic member and outcrops well up on the side of the South Cave Hills mesa. Its topographic location has probably prevented its exploitation. The only bed from which lignite has been mined is near the top of the lower part of the Lance and outcrops along the valley of Bull Creek.

The exact correlation of the several sections measured in this township is difficult because of the lack of exposures and the variability of the lignite beds. Four valuable beds in the Ludlow member of the Lance are exposed at location 70, in the north face of the South Cave Hills, but at no other place in the township is there so complete a section revealed.

Three sections in secs. 14 and 15 represent the lowest beds exposed. At each of locations 90A and 91, in the NW. ¼ sec. 14, 2 feet of dirty lignite occurs. It is probable that the upper and lower beds at location 80 are the same as those at locations 90A and 91, respectively.

number of red-capped hills. The total relief in the township is 450 to 500 feet; the lowest points are near the Riley ranch, in sec. 24, and near Cox post office, in sec. 4, and the highest points on top of the North Cave Hills in secs. 21 and 36, where the altitude is about 3,450 feet above sea level.

The northern and eastern parts of the township are drained by Crooked Creek and its tributaries, and the southwestern part by Camel Creek. Crooked Creek, which is fed by numerous springs that issue from the lignite beds or from the base of the rim rock of the Cave Hills, is one of the few perennial streams of the region. Springs yielding small streams of pure cold water occur near the Cox ranch, in sec. 3, the Craig ranch, in sec. 17, and the Riley ranch, in sec. 24, as well as at other places in all parts of the township. The water from these springs contains little or no alkali, because the rocks from which it issues are calcareous and contain but a very small percentage of alkaline salts. A number of well-known ranches are situated in different parts of this township, and outside of the Sioux National Forest homesteaders have recently taken up claims and are attempting to farm the land.

The lowest rocks exposed in the vicinity of the Cave Hills consist of shale, sandstone, and lignite beds belonging to the Lance formation. The shale is dark in color and somewhat sandy and weathers to a semigumbo soil that supports only scanty vegetation. The rocks are decidedly cross-bedded and vary greatly in composition. The shale contains a large number of iron carbonate nodules of varying size, the largest several inches in diameter. In shape they are roundish, elongated, or flat. These nodules on an oxidized surface are brown to reddish, but on fresh fracture have a light-gray or drab color. The Ludlow lignitic member of the Lance, which includes nearly all of the formation exposed in this township, is more sandy, lighter in color, and more evenly bedded than the lower part of the Lance and contains all the valuable lignite beds.

The Lance formation is overlain by the Fort Union formation, which is composed of 250 to 300 feet of massive sandstones, with about 20 feet of light-colored sandstone near the middle and a thin bed of quartzite near the top. The line between the Lance and the Fort Union formation is placed at the base of the sandstone that forms the rim rock of the Cave Hills.

Two small areas of green conglomerate, each a few square rods in extent, are present in secs. 21 and 28 and are assigned doubtfully to the White River formation. The correlation is based on the lithologic character of the beds, as no fossils were found in them. The conglomerate contains green, reddish, and white pebbles, ranging in size from a quarter of an inch to 1¼ inches, and seems to be entirely

different from anything found in the Fort Union. Fragments of chert similar to those common to the White River formation are associated with the conglomerate rocks.

The beds in general dip about 25 feet to the mile toward the southeast, but a mile north of the Craig ranch the attitude of a lignite bed indicates a slight northerly dip. In the neighborhood of the Riley ranch a bed of lignite apparently disappears beneath the creek bed both above and below the ranch house, thus indicating a slight anticline with the axis running northwest and southeast.

There are, in addition to several thin beds, three valuable beds of lignite, the Riley, the Craig, and the T Cross, which were mapped in detail. The lowest and poorest of these is the Riley; the highest and most valuable the T Cross. The Riley bed is 11 feet 3 inches thick at location 211 (see Pl. VI), near the Riley ranch, in sec. 24, where for many years it has been mined for local use. The lignite is of excellent quality, but the bed appears to be decidedly lenticular, for at location 288, in the SW. ¼ NE. ¼ sec. 18, T. 22 N., R. 6 E., about 1½ miles below the Riley ranch, it has been prospected in the creek bottom and is only 3 feet 4 inches thick. The same bed as exposed farther north (location 287) and west (location 289) is of little value. (See Pl. VI.)

About 50 feet above the Riley bed is the Craig lignite bed, which is exposed at locations 213, 231, and 215, along the east side of the Cave Hills, in secs. 3, 11, and 14. Locations 220, 221, 203, and 204 are thought to be on the same bed. Its thickness ranges from 1 foot 10 inches at location 204, in sec. 34, to 6 feet 11 inches at location 231. Detailed measurements of the bed at these places are given on Plate VI. To the west, in secs. 17 and 18, there are small burns along its outcrop, and still farther west, in the adjacent township, the bed is of little value.

The T Cross bed of lignite occurs about 100 feet above the Craig bed. Its identification from place to place is uncertain, but the correlation as shown on the map (Pl. I, in pocket) seems to be the best that could be made. The bed in the southern part of the township, along Camel Creek and its tributaries at locations 192, 193, 196, 197, 198, 199, 200, 201, 202, and 212, is 3 feet 11 inches or less in thickness, but at location 205A it is 5 feet thick. Along Crooked Creek and its tributaries north and east of the Cave Hills the bed is thicker and better in quality. It ranges in thickness from 9 feet 1 inch at location 209 to 3 feet 6 inches at location 218 and has been mined at locations 209, 208, 219, 218, and 218A. This bed is about 3,050 feet above sea level and dips to the east about 20 feet to the mile. It is correlated with the Giannonatti bed, exposed in T. 21 N., R 7 E., and with the T Cross bed as exposed at Ives, N. Dak.

About 60 feet above the T Cross there is another lignite bed, which, along the east side of the Cave Hills, at locations 226, 227, 228, and 230, ranges in thickness from 2 feet (location 228) to 4 feet 4 inches, but is separated into two benches by 4 inches of shale (location 226). The bed is not exposed to the south unless it is represented by a thin bed which at locations 206, 207, and 205 is from 1 foot to about 2 feet 5 inches thick. Near the ranger cabin at location 216, in sec. 10, 2 feet 5 inches of lignite is exposed, and on the north face of the ridge, at location 223, in sec. 18, there is a bed more than 5 feet thick. The approximate position of the upper lignite is immediately below the cliff. At location 222 6 feet of lignite is exposed in a mass of slumped material, which possibly came from the upper bed. Along the ridge between Camel and Bull creeks a lignite bed 2 feet thick at location 195 and 1 foot 4 inches thick at location 194 is apparently between the T Cross and the upper bed. Detailed measurements of the lignite beds in this township are given on Plate VI.

T. 23 N., R. 5 E.

T. 23 N., R. 5 E., is for the most part drained by Crooked Creek and has a rough surface that culminates in the noted landmark, Eagles Nest. Cox post office is in the SE. ¼ sec. 33.

The Lance formation underlies the township, with the exception of Eagles Nest Butte, and is composed of somber-colored shale interbedded with arenaceous shale and sandstone. The rocks are in many places markedly cross-bedded and show very irregular deposition. On weathering this formation gives rise to a very poor soil. The upper portion of the Lance, the Ludlow lignitic member, is somewhat more sandy than the lower portion and carries the only valuable bed of lignite.

The only representative of the Fort Union formation, a heavy-bedded and resistant yellow to gray sandstone 100 feet thick, caps Eagles Nest, in sec. 27. At some places the sandstone is cross-bedded, and locally it is conglomeratic. On weathered surfaces it is decidedly uneven, with numerous large rounded cavities.

Three beds of lignite crop out in the township. The lowest and thinnest is exposed in a boggy place at location 234, in sec. 22, where an accurate measurement could not be obtained, but it is at least 2 feet 6 inches thick. Elsewhere this bed could not be found. Higher beds underlie small hills northeast of Eagles Nest. At location 233 (see Pl. VI) the following section is exposed:

Section at location 233, in the SW. ¼ sec. 23, T. 23 N., R. 5 E.

	Ft.	in.
Shale, brown, carbonaceous and fissile	1	4
Bone		2
Shale, brown, carbonaceous		1
Lignite	1	4
Shale, black, carbonaceous		1
Lignite	1	9
Shale, brown, carbonaceous	16	10
Shale, brown, carbonaceous and fissile, with lenses of lignite as much as 2 inches thick	1	3
Shale, brown, carbonaceous	8	8
Lignite	3	0
	34	6

A few loads of lignite have been removed from the lower bed at this place. The T Cross bed of lignite crops out in Eagles Nest, and the following section is exposed in a prospect at location 232, on the northern slope:

Section of lignite bed at location 232, in sec. 27, T. 23 N., R. 5 E.

	Ft.	in.
Shale, black, carbonaceous.		
Lignite, very impure		2
Lignite		11
Lignite, impure		9
Lignite, fair quality	1	8
Shale, dark, sandy.		
	3	6

There are at many localities in the northwestern part of the township large masses of red baked rock, probably formed by the burning of this bed, but coal of this bed underlies only small areas in that vicinity. Direct correlation of the beds exposed at locations 232 and 233 is impossible, because in the intervening area the rocks are badly concealed by grassy slopes.

TPS. 16, 17, 18, 19, AND 20 N., R. 6 E.

The entire area of Tps. 16, 17, 18, 19, and 20 N., R. 6 E., with the exception of T. 16 N. and part of T. 17 N., which are drained by Moreau River, lies in the valley of South Fork of Grand River and its tributaries Squaw, Sandy, Jones, and Bull creeks. South of the South Fork of Grand River the surface rises gradually in a sandy, more or less grass-covered plain to the divide in the southern part of T. 17 N., then slopes more abruptly to Moreau River, which flows eastward near the middle of T. 16 N. A few small areas of sand dunes and badlands are scattered over the part south of the South Fork of Grand River, but most of the surface is grass-covered and used exclusively for stock raising. A few high buttes along the divide

north of the South Fork of Grand River are capped by resistant sandstone ledges and rise abruptly above the general level of the prairie.

Throughout nearly the entire area the surface rocks belong to the lower part of the Lance formation, the Ludlow lignitic member being represented in only a few elevated areas in Tps. 19 and 20 N. The soft sandy shale and friable sandstone weather easily to sandy soil, which obscures the bedrock except at a very few places. The strata dip gently to the northeast.

Lignite is exposed at only a few places in these townships, and from the general character of the rocks that underlie the area it is concluded that there are no beds of value except those whose outcrop is shown on Plate I (in pocket). Thin beds of lignite are exposed in the sides of two small buttes in secs. 4 and 10, T. 19 N. At location 235, in sec. 10, there is a bed 1 foot 6 inches thick; at location 236, in sec. 4, there are two beds, the upper, which is 1 foot 3 inches thick, about 40 feet above the lower, which is 1 foot thick.

A flat-topped butte in sec. 31, T. 20 N., is underlain by several feet of black shale, brown shale, and thin bands of lignite that is too poor to be used for fuel. At location 237, in sec. 21, a bed of lignite 1 foot thick is exposed at the base of the Ludlow lignitic member of the Lance. A thicker bed underlies a small area in secs. 1 and 2. At location 238 (see Pl. VII) the following section is exposed:

Section of lignite bed at location 238, in the NW. ¼ sec. 1, T. 20 N., R. 6 E.

	Ft.	in.
Shale.		
Lignite, dirty	1	6
Lignite		10
Sand		½
Lignite, dirty		5
Shale		3
Lignite		6
Shale.		
Total section	3	6½
Total lignite	3	3

This bed increases in thickness toward the east, and is 5 feet 6 inches thick at location 396, in sec. 6, T. 20 N., R. 7 E.

T. 21 N., R. 6 E.

There is a difference in elevation of about 500 feet between the top of the Cave Hills, in sec. 7, T. 21 N., R. 6 E., and the lowland along Jack Creek, about 2,900 feet above sea level, near the Van Horne ranch, in sec. 33. The low grassy divide between Big Nasty Creek on the north and Jack Creek on the south extends from the Cave Hills escarpment, in secs. 6 and 7, southeastward through the township. In the east-central portion the divide consists of a high,

flat mesa, due to a comparatively resistant sandstone that forms the cap. The valley of Big Nasty Creek, which traverses the north tier of sections from west to east, is broad, open, and grass-covered. The most conspicuous topographic feature is the North Cave Hills, which project into sec. 7, but lie for the most part to the northwest. These hills stand out prominently, because they are capped by a very massive sandstone some 100 feet in thickness, which resists erosion and forms a nearly vertical cliff around the margin of the mesa.

The Pelham ranch, in sec. 6, and the Van Horne ranch, in sec. 28, are well-known landmarks of this part of the field, and until recently constituted nearly the entire settlement. A few homesteaders have recently taken up tracts of land, but as a whole the township is better suited to grazing than farming.

Of the 500 feet of rock strata exposed, the lower 400 feet belongs to the Lance formation, which underlies the entire township except a small part of sec. 7. The lower 100 feet or so is composed of irregularly bedded sandy shale and sandstone, with a few beds of lignite. The upper 300 feet of the Lance formation carries the only valuable lignite beds, and is differentiated from the rest of the formation as the Ludlow lignitic member. It consists of sandy shale with a considerable amount of interbedded light-colored sandstone and lignite. The individual beds are more continuous than those of the lower part of the formation. The ridges in the east-central part of the township are capped by thin resistant sandstones, which protect the underlying soft shale and give rise to rugged topography.

The rim rock of the Cave Hills is a massive sandstone, about 100 feet thick, which is assigned to the Fort Union formation. It is light buff or yellow, in some places grayish, rather coarse grained, and loosely cemented. The upper part is somewhat more resistant than the lower and protects it from rapid disintegration. Ludlow Cave, in sec. 7, is a cavity in the massive sandstone, formed by the combined action of wind and water.

The strata are essentially horizontal and for most purposes may be so considered, the dip being too slight to be a serious factor in any mining operation. There is in sec. 8 an apparent local dip of about 3° SE., with a strike slightly north of east. In general the formations seem to have a very slight northeastward dip amounting to about 23 feet to the mile.

Two good lignite beds are exposed in this township. The lower is probably the same as the Widow Clark lignite of T. 21 N., R. 7 E., and its outcrop was traced in considerable detail and with a fair degree of accuracy. In the gullies leading down from the Cave Hills, in the northwest corner of the area (sections 253 to 258A, Pl. VI), the bed ranges in thickness from 1 foot 7 inches at location 255 to 3

feet 8 inches at location 254. To the east the bed thickens rapidly and at location 251, in sec. 15, it is 8 feet 8 inches thick. Along its outcrop, in the southeast quarter of the township, the thickness ranges from 3 feet 2 inches at location 242 to 6 feet 8 inches at location 248. At location 241b, in sec. 36, the bed is represented by 3 feet 10 inches of lignite, split by 5 feet of shale. Detailed sections measured along the bed are represented on Plate VI by Nos. 241b, 242, 243b, 245, 247b to 258, 258A, 261b, 262b, and 263. The lignite is not exposed along the south side of Big Nasty Creek because of the thick grass covering the slopes, but at one point in sec. 10 there is a slight burn which was considered to be on the bed. Strip mines have been operated at location 253, in sec. 8, and location 263, in sec. 24.

The upper valuable bed of lignite is separated from the lower by 20 to 40 feet of strata. It has burned at many places in the southeast corner of the township and also in sec. 12, giving rise to large masses of clinker. This bed is correlated with the Giannonatti bed in the township to the east, with the main bed around the northern extremity of the North Cave Hills, and with the T Cross bed at Ives, N. Dak. Sections of the bed at locations 239, 240, 241a, 243A, 244, 247a, 261a, 262a, 243a, 264, 265, 265A, 266, 267, and 268 (see Pl. VI) show that it ranges in thickness from 4 feet 1 inch at location 243a to about 12 feet 6 inches at location 239. Its cover reaches a maximum thickness of about 150 feet. The bed is correlated with the one containing 7 feet of lignite at the Pelham mine at location 268, in sec. 6. East of location 268 grass-covered areas conceal the outcrop of the bed, except at two localities in the SE. ¼ sec. 6 and the NE. ¼ sec. 7, where its presence is indicated by red burned rock.

A thin lignite bed outcrops at location 269, in the SW. ¼ sec. 1, and in detail is as follows:

Section of lignite bed at location 269, in the SW. ¼ sec. 1, T. 21 N., R. 6 E.

	Ft.	in.
Shale.		
Lignite		11
Shale		2
Lignite	1	1+
	2	2+

The entire thickness of this bed could not be measured because it was partly covered by water. Another unimportant lignite bed outcropping in the SW. ¼ SE. ¼ sec. 9 is, at location 259, 3 feet 2½ inches thick, with a thin shale parting near the middle. It does not continue as a thick bed for any great distance. Thin streaks of lignite at lower horizons are exposed in the creek bank in the SE. ¼ sec. 22. The following section was measured at location 246:

Section of lignite bed at location 246, in the SW. ¼ sec. 22, T. 21 N., R. 6 E.

	Ft.	in.
Shale.		
Lignite		9
Shale		3
Lignite		5
Shale		7
Lignite		10
Total section	2	10
Total lignite	2	0

Farther up the creek, in sec. 15, some thin beds occur but were not traced. At location 260, in sec. 25, there is 2 feet 8 inches of lignite, split by 3 inches of shale. No correlation of these isolated outcrops is attempted.

No samples for analysis were procured from any of the beds in this township, but the two principal beds are lignite of good quality. They have not been developed commercially to any extent, but there are three small strip pits where lignite has been obtained by the inhabitants for local use. Prospects on the lower bed have been opened in sec. 8 (location 253) and sec. 24 (location 263), and there is a small strip pit on the upper bed near Pelham's ranch at location 268, in sec. 6.

T. 22 N., R. 6 E.

A high, irregular ridge, with well-defined northward-facing slopes, extends from the Cave Hills, in secs. 30 and 31, T. 22 N., R. 6 E., to the Tepee Buttes, in sec. 6 of the township to the east, and separates the drainage of Crooked Creek on the north from that of Big Nasty Creek on the south.

A large part of T. 22 N., R. 6 E., is rolling and grass-covered, but badlands are developed locally and some conspicuous buttes stand out like monadnocks above the surrounding country. The butte in sec. 19 rises to an altitude of 3,777 feet above sea level. Three buttes in secs. 19 and 27 are capped by very hard quartzite which protects the underlying rocks from rapid erosion. Other buttes in secs. 16 and 31 are capped by the massive sandstone that forms the rim rock of the Cave Hills.

There are a few small springs in the township, and Crooked Creek contains running water throughout the greater part of the year. Water for domestic use is obtained chiefly from wells and is almost everywhere reached at rather shallow depths—20 to 30 feet. Nearly all the water is alkaline. A large part of the land has been taken up by homesteaders, but there are at present very few inhabitants. The little hamlet of Ludlow is located in the southwest corner of sec. 35.

A total thickness of about 600 feet of strata is exposed in this township. The lower part of the Lance formation, consisting of soft

dark-colored shale and sandstone with a single bed of lignite, is exposed along Crooked Creek, in the northern part. The rocks are decidedly cross-bedded and vary greatly in character, containing in places a great number of iron carbonate nodules which weather to dark-brown masses. The Ludlow lignitic member, which here includes all the upper part of the Lance, contains more yellow sandstone and sandy shale than the lower part and also includes all the valuable lignite beds. Where the sandstones are indurated they form gnarly outcrops, but elsewhere they weather to sandy slopes. The Fort Union formation, which is exposed in several high buttes, consists of about 235 feet of yellow and red sandstone similar to that on the Cave Hills, some shale, and a peculiar quartzite bed, bowlders from which are scattered abundantly over the surface.

The rocks in general dip eastward at about 30 feet to the mile, but in one or two localities minor folds have been developed. One of these occurs in the southwest corner of sec. 28 and seems to be a small anticline with its axis running nearly east. There is further evidence of the anticline in secs. 19 and 30, on the west side of the township.

The lowest bed of lignite occurs near the top of the lower part of the Lance formation and outcrops in the northern part of the township, in the valleys of the small tributaries of Crooked Creek. At location 290, in sec. 19 (see Pl. VI), the bed contains 6 feet 2 inches of lignite, but within a few rods it disappears beneath the creek, to reappear about a mile downstream. Sections 287, 288, and 289, exposed in secs. 7 and 18 (see Pl. VI), are supposed to represent the same bed and show an average thickness of more than 3 feet. At these places the bed is not so thick as the one exposed at the small mine near the Riley ranch, at location 211, in sec. 24 of the township to the west. Small strip mines have been opened at locations 288 and 289, in sec. 18.

Lignite beds in the Ludlow lignitic member of the Lance are exposed at a large number of places in the township, and at other places the outcrop of beds is indicated by baked rock that has resulted from the burning of lignite. Grassy slopes and rock slumps prevent the exact correlation of beds, but that indicated on the map (Pl. I, in pocket) seems to be the best. Beds at locations 272, 274, 275, 275A, 275B, 276, 277, 278, 285, 285A, and 286 are near the base of the member and range in thickness from 2 feet at location 285A to 8 feet 9 inches at location 274. Along the outcrop line joining these sections there are numerous areas of fused red rock, which are at the same horizon. The variation in thickness of this main bed is shown in detail on Plate VI.

In sec. 14 there are two beds above the main lignite. One, stratigraphically 70 feet higher (at location 284), contains 5 feet of lignite,

and 25 feet above this is a second bed more than 2½ feet thick that has been prospected at location 282. In a well at location 283, in the SE. ¼ sec. 14, 4 feet 6 inches of lignite was found at approximately the horizon of the middle bed. No lignite was found farther northeast in this township at either of these horizons. To the west, at location 281, in sec. 16, the middle bed is split by a shale parting into two benches and is nearly worthless. (See Pl. VI.) A bed in the southwestern part of the township, shown in sections 270, 271, 272, 279, and 280, lies about 20 feet above the main bed. At location 273 this bed is represented by 2 feet of lignitic shale.

Two beds of lignite 20 feet apart are exposed in a narrow valley in the southeast corner of the township. The lower, shown graphically by sections 298, 299, 300, and 301 (Pl. VI), reaches at location 299 a maximum thickness of 5 feet 6 inches; elsewhere, so far as ascertained, the bed is worthless. It is possible that the bed outcropping in sec. 33 and represented by section 291 is at the same horizon. The upper bed in this part of the township is exposed at locations 292, 293, 294, and 295, but it is not especially valuable. (See graphic sections, Pl. VI.) Lignite beds 3 feet and 5 feet thick at locations 296 and 297, respectively, are reported in wells and may correspond to the upper bed just described. The exact relation of the beds in the eastern part of the township to those exposed elsewhere is not known, but it is probable that the upper bed here is to be correlated with the bed represented by sections 279 and 280.

T. 23 N., R. 6 E.

The nortnern part of T. 23 N., R. 6 E., drains northward into the tributaries of the North Fork of Grand River, and the remainder into Crooked Creek, which meanders in a broad, open valley, and traverses the southern and eastern parts of the township from west to northeast. Through the middle of the area extends a low, rolling grassy divide. During the greater part of the year there is running water in Crooked Creek, but the other streams are intermittent. Nearly all the water for farm use is obtained from shallow wells, most of which yield alkaline water. In the NW. ¼ sec. 20 there is a small spring of good water. Although most of the tillable land has been homesteaded, the township has now only a few inhabitants.

The rocks exposed in this township belong to the Lance formation and are about 200 feet thick. They consist chiefly of dark shale interbedded with sandstone, one or two beds of lignite, and beds of carbonaceous shale. The upper portion of the exposed geologic section (the Ludlow lignitic member) contains a large amount of sandstone which weathers into irregular forms. The sandstone is somewhat lighter in color than the shale. being gray, yellow, and

buff. The rock strata dip eastward at about 15 or 20 feet to the mile, as determined by the altitudes of certain beds in this and adjacent townships.

Only one bed of lignite of any value is exposed, and measurements of this bed were obtained at locations 302, 303, 304, and 305. (See Pl. VI.) The bed is the thickest at location 305 and thins to the south and east. East of location 304 the bed is not exposed, but near the northeast corner of sec. 21 considerable quantities of lignite have been dug up by prairie dogs. There is no evidence of the bed on the east slope of the divide in secs. 22 and 7, but at location 302, in the SW. ¼ sec. 27, 2 feet of poor lignite is exposed. At location 303, in the SE. ¼ NE. ¼ sec. 28, there is a section very similar to the one at location 304. It is said that in a well in the SW. ¼ sec. 28 a few inches of lignite was found. Another well, on the south side of sec. 20, encountered lignite at a depth of 22 feet. There is 1 foot 10 inches of poor lignite exposed at location 306, on the north side of sec. 29, which may be at the same horizon.

T. 16 N., R. 7 E.

T. 16 N., R. 17 E., is drained entirely by the North Fork of Moreau River, which flows eastward across the southwestern part. The surface of the township is rolling and grass covered, except in the northeast corner, where the Slim Buttes rise more than 600 feet above the general level of the country. The top of the mesa is level and grass covered and is surrounded by a nearly vertical sandstone cliff. Below this cliff is a zone of deeply cut badlands, in which, except at a few places, slumps effectually conceal the character of the strata on the lower slopes.

The sandstone cap of the Slim Buttes belongs to the Arikaree (?) sandstone, and below it are clay and sandstone of the White River formation. At the south end of the Slim Buttes, in this township, the White River formation rests on the lower part of the Lance formation, but to the north the basal portion of the Ludlow lignitic member of the Lance is exposed. The strata dip northeastward, and the increase in thickness of the Ludlow lignitic member toward the north is due to this northeasterly dip, rather than to inequality of the erosion surface upon which the White River formation was deposited.

Lignite in the lower part of the Lance formation is exposed at three localities in secs. 12 and 13. At location 307, in sec. 13, there is 1 foot 10 inches of very dirty lignite; at location 308 a bed containing 2 feet 2 inches of dirty lignite is exposed; and at location 309 there is 2 feet 5 inches of dirty lignite at a horizon several feet below that of the bed exposed at location 308.

Because of the large amount of slumping which has taken place around the Slim Buttes, lignite beds can be seen in only a few places and such beds as are exposed can not be correlated with certainty. Less than 50 feet above the base of the Ludlow lignitic member of the Lance is a thick mass of brown and black shale with several thin beds of lignite (location 312). The highest bed has burned, leaving only a bed of red baked clay, so that the original thickness of the bed can only be estimated.

Sections of the Ludlow lignitic member in secs. 1 and 2, T. 16 N., R. 7 E.

Location 312.

	Ft.	in.
Clay.		
Lignite, burned; thickness unknown.		
Clay	5	0
Lignite		3
Clay	1	4
Sandstone	7	0
Shale, brown	1	0
Shale, black, carbonaceous		3
Lignite		9
Shale, brown		1
Lignite		9
Bone		2
Clay	8	0
Lignite, dirty	2	2
Shale, black, carbonaceous		1
Lignite		5
Clay		10
Bone		5
Clay	1	5
Lignite	1	6
Shale, brown		6
Lignite		3
Shale, black, carbonaceous		2
Lignite		11
Shale, brown		10
Lignite		4
Clay.		
Total section	34	5
Total lignite	7	4

Location 310.

	Ft.	in.
Shale.		
Lignite, dirty	2	11
Bone		3
Shale, brown and black, partly carbonaceous	22	0
Lignite, dirty	1	10
Shale, brown to black, partly carbonaceous	2	8
Clay.		
Total section	29	8
Total lignite	4	9

Location 311.

	Ft.	in.
Clay.		
Lignite	2	3
Clay.		

T. 17 N., R. 7 E.

Along the east side of T. 17 N., R. 7 E., the Slim Buttes mesa rises in an almost vertical cliff to an altitude nearly 600 feet above that of the surrounding plain. The top of the mesa is gently rolling, and upon it there is a heavy growth of grass and a few pine trees; the trees are most abundant about the margin. Around the mesa is an area of slumped rocks which recent erosion has dissected at a

number of places into nearly impassable badlands. The surface of the western two-thirds of the township is gently undulating, having numerous small valleys through which the run-off from the area finds its way to the South Fork of Grand River on the north and to Moreau River on the south. The soil, which in a large part of the township is the result of the disintegration of the sandy shale and soft sandstone of the lower part of the Lance formation, is of fair quality and is being cultivated by a number of farmers. Numerous springs issue from a sandstone near the base of the Slim Buttes and furnish excellent water in sufficient quantity to be used for irrigating small patches of land in the plains area to the west.

All the main stream valleys are cut into the lower part of the Lance formation, but the Ludlow lignitic member caps a few of the higher divides and outcrops in a narrow belt along the slope of the mesa. The White River formation, resting unconformably upon the Ludlow lignitic member of the Lance, is composed of flesh-colored and yellow clay and white sandstone, locally conglomeratic. Numerous fossil bones found in these rocks prove the formation to be of Oligocene age. Above the White River, and possibly unconformable to it, is a heavy-bedded, almost homogeneous sandstone which is assigned to the Arikaree (?) sandstone. No fossils have yet been found in this sandstone, and its age is determined solely on lithologic character. The strata dip gently in a direction slightly north of east.

All the lignite in this township is in the Ludlow lignitic member of the Lance. The individual beds are probably not continuous over large areas, but where one pinches out another or several others may appear in the section, so that wherever the strata are well exposed one or more beds may be seen. Although there is sufficient lignite exposed at several localities to warrant mining, the demand for fuel is not great and only two small strip mines have been opened. At the Red Butte mine (location 315; see Pl. VII), in sec. 35, lignite is mined from the upper bed, and at the Mendenhall mine (locations 325 and 326), in sec. 1, the middle and lower beds are worked. Analyses 13222 and 13220 (p. 42) show the quality of the lignite in the two beds, respectively. The beds were measured at a number of places along the west face of the Slim Buttes, and the following table shows their thickness and correlation:

Sections of lignite beds in T. 17 N., R. 7 E.

No. on Pl. I.	Location.	Bed.	Section.	Ft.	in.
313	SE. ¼ sec. 35	Middle and lower	Clay.		
			Lignite, dirty	1	9
			Shale, brown	2	1
			Lignite		6
			Shale, black to brown	1	7
			Lignite		3
			Shale, brown		1
			Lignite		3
			Shale.		
			Total section	6	6
			Total lignite	2	9
314	do	Highest	See Plate VII.		
315	NE. ¼ sec. 35	do	Do.		
316	SW. ¼ sec. 26	Middle and lower	Shale, brown, with thin bands of lignite	10	0
317	NW. ¼ sec. 26	Upper	Sandstone.		
			Shale, carbonaceous		3
			Lignite, dirty	4	8
			Shale.		
			Interval	12	
		Middle	Lignite, dirty	2	8
			Total section	19	7
			Total lignite	7	4
318	do	Lower	Lignite, dirty	2	0
319	do	Upper	See Plate VII.		
320	SE. ¼ sec. 23	do	Do.		
321	NE. ¼ sec. 23	do	Do.		
322	SW. ¼ sec. 13	do	Do.		
323	NW. ¼ sec. 12	do	Lignite, dirty	2	4
324	do	do	Lignite, dirty	2	6
			Interval	10	0
		Middle	Lignite	1	0
			Total section	13	6
			Total lignite	3	6
325	SW. ¼ sec. 1	Middle and lower	See Plate VII.		
326	SE. ¼ sec. 1	Upper	Do.		
327	Sec. 2	Uncorrelated	Lignite, dirty	2	6

T. 18 N., R. 7 E.

Several streams flowing in wide valleys converge toward the northwest corner of T. 18 N., R. 7 E., where they join to form Squaw Creek. Sioux Creek, one of the largest, heads in Reva Gap, in the Slim Buttes. Between the streams are fairly high divides capped by rocky points. The northeast and southeast corners of the township are occupied by parts of the high Slim Buttes mesa, which stands about 600 feet above the general level of the plains. Numerous good springs issue from rocks along the edge of the mesa, and several large stock ranches have been so located as to take advantage of the excellent water. Only a small part of the area is cultivated.

The lower part of the Lance formation outcrops in the stream valleys, and the Ludlow lignitic member caps the divides and outcrops around the Slim Buttes. The Ludlow in turn is overlain unconformably by clay and conglomeratic sandstone of the White River formation. The highest formation exposed, making the cliff of the buttes, is a fine-grained whitish sandstone which is supposed to belong to the Arikaree (?) sandstone. The lignite-bearing strata dip gently to the northeast.

The more valuable beds of lignite outcrop around the borders of the Slim Buttes in the Ludlow lignitic member of the Lance. These beds vary considerably in thickness from point to point, as do also the distances between them. The section at location 333 (see Pl. VII), in the SW. ¼ sec. 24, probably includes all the beds and may be considered typical for the southwestern part of the township. It comprises three beds of lignite more than 4 feet thick and two thinner beds. Eastward from that place the strata are concealed for about a mile, and where they are exposed again at location 334, in sec. 24, each of the beds is only 2 feet or less in thickness. The section is as follows:

Section of lignite beds at location 334, in the SE. ¼ sec. 24, T. 18 N., R. 7 E.

	Ft.	in.
Clay.		
Lignite	1	11
Clay	9	0
Lignite	1	0
Shale, brown, sandy, carbonaceous	15	0
Lignite, somewhat dirty	2	0
Shale.		
Total section	28	11
Total lignite	4	11

South of location 333 both the lower beds of that section are exposed at location 322 and the lowest bed at locations 330 and 328. At location 328 the bed is 13 feet 8 inches thick and is the thickest bed in this part of the field. The bed is separated into two benches by 1 inch of shale, which presumably thickens toward the south, so that the single bed at location 328 represents the two lower beds at locations 325 and 326, in the township south of this one. The middle bed of section 333 is exposed at location 331 and is probably represented by the two beds at location 329. These beds are 7 feet 10 inches and 3 feet 11 inches thick, and are separated by only 3 feet 1 inch of shale and sandstone. The detailed sections at all these points are shown in Plate VII.

North of Sioux Creek, on the east side of sec. 1, four beds of lignite are exposed within a stratigraphic distance of about 100 feet. The highest is nearly 12 feet thick and is represented on Plate VII by

section 335. Ten feet below is a bed which is 2 feet 6 inches thick (location 336), and 45 feet below is a third bed of dirty lignite (location 337), 2 feet 4 inches thick. The bed exposed at location 338 is the lowest in the section and contains 2 feet 6 inches of excellent lignite. In another gully, less than half a mile farther west, the two upper beds are absent and the base of the White River formation is considerably lower. This seems to indicate that erosion had produced a rather irregular surface in this vicinity before the White River sediments were deposited. The two lower beds are poorly exposed, but both appear at location 339, in the SW. ¼ sec. 1, where the upper of the two is 2 feet thick and the lower 1 foot 9 inches thick and of good quality. Half a mile farther west, at location 340, each bed is less than a foot thick. Northwestward beyond this point the beds could not be followed and are presumably absent.

Below the beds described is a lens 2 feet 2 inches thick, occurring in sec. 5 at location 341, at the base of the Ludlow lignitic member of the Lance formation. At about 50 feet below this bed, in the lower part of the Lance, the following section is exposed:

Section of lignite beds at location 342, in the SE. ¼ sec. 4, T. 18 N., R. 7 E.

	Ft.	in.
Shale.		
Lignite	2	3
Shale, brown	4	7
Lignite, dirty	3	0+
Total section	9	10+
Total lignite	5	3+

The bottom of the bed was covered by water, preventing complete measurement. This bed is not present along the valley to the south of Sioux Creek and is covered by wash north of location 342, but it is probably the same bed as the one exposed at location 343, in the township to the north.

T. 19 N., R. 7 E.

The South Fork of Grand River crosses the northwestern part of T. 19 N., R. 7 E., in a wide sandy valley and receives the drainage of the whole area north of the Slim Buttes. These buttes, which rise about 600 feet above the general level of the surrounding country, occupy the southeastern part of the township. North and west of the buttes the surface is deeply dissected into intricate badlands. Numerous prominent ridges and buttes are capped by the resistant red clinker caused by the burning of lignite beds and form striking features of the area. Slumps are especially common about the edge of the mesa, in many places obscuring the lignite beds. Numerous springs occur at the base of the Slim Buttes, but the rugged nature of the surface in their vicinity has prevented the

establishment of ranches or farms that could take advantage of the water. Only a very small part of the township is suitable for cultivation.

The main valleys are cut into the lower part of the Lance formation, and the Ludlow lignitic member outcrops along the divides and in a narrow belt about the foot of the buttes. The Ludlow is overlain unconformably by the non lignite-bearing conglomeratic sandstone and clay of the White River formation, and these in turn by the fine-grained Arikaree (?) sandstone.

The lignite-bearing beds dip gently to the northeast. Several beds of lignite, all of rather poor quality and of slight extent, crop out in the township. The lowest bed is near the top of the lower part of the Lance formation and is thought to be the same bed as the one on which section 342 was measured, in T. 18 N., R. 7 E. At location 343, in sec. 33 of this township, it is thicker than to the south, but poor in quality. (See Pl. VII.) To the north the bed thins and is not exposed in the valley in secs. 27 and 28, but at locations 344, 345, and 346 sections were obtained, and the lens at location 347, in sec. 22, is supposed to represent the same bed.

Sections of beds along lowest lignite horizon in T. 19 N., R. 7 E.

Location 344. NE. ¼ sec. 29.

	Ft.	in.
Shale.		
Lignite	1	3
Shale, brown	1	6
Lignite	1	11
Shale.		
Total section	4	8
Total lignite	3	2

Location 345. SW. ¼ sec. 20.

	Ft.	in.
Shale, brown.		
Lignite		10
Shale, carbonaceous	2	0
Clay	10	0
Shale, brown	1	0
Lignite		10
Shale.		
Total section	14	8
Total lignite	1	8

Location 346. NE. ¼ sec. 21.

	Ft.	in.
Shale, brown.		
Lignite	1	4
Shale, brown		6
Lignite		5
Shale.		
Total section	2	3
Total lignite	1	9

Location 347. NE. ¼ sec. 22.

	Ft.	in.
Clay.		
Lignite, dirty		9
Clay, gray, with thin bands of lignite	4	6
Lignite	1	4
Lignite, very dirty		9
Clay.		
Total section	7	4
Total lignite	2	10

A bed of lignite at the base of the Ludlow lignitic member of the Lance is exposed at three places. At location 352, in sec. 15, it is represented by a thick bed of shale with 10 inches of lignite; at location 353, in sec. 23, it is represented by 1 foot 6 inches of lignite, with a 3-inch shale parting 6 inches from the top. A more extensive lens has considerable lignite at locations 355 and 356, in sec. 12 (see Pl. VII), and at location 354, in sec. 13, there is 2 feet 3 inches of lignite with a 2-inch shale parting in the middle.

Several isolated outcrops, probably representing small lenses of lignite, occur higher in the Ludlow member. Three of these are exposed in a gully in the south side of sec. 26; the lowest, at location 360, is 1 foot 1 inch thick; the next, at location 359, contains 1 foot 7 inches of poor lignite; and the upper, at location 358, contains 2 feet 1 inch of good lignite. At location 365, in the northwest corner of sec. 24, the following measurement of a lignite bed near the base of the Ludlow member was made:

Section of lignite bed at location 365, in sec. 24, T. 19 N., R. 7 E.

	Ft.	in.
Clay, gray.		
Lignite		5
Clay	2	0
Lignite, dirty		4
Lignite	1	0
Lignite, dirty		9
Clay.		
Total section	4	6
Total lignite	2	6

At location 357, in the southwest corner of sec. 14, there is a bed 1 foot 6 inches thick, probably the same as that underlying the ridge in the center of the township, along which sections 348, 349, 350, and 351 were measured. The cover above the bed at these four locations is not great, so it is probable that the lignite has deteriorated considerably through oxidation and is of little value. In a small strip pit at location 351, in sec. 9, there are two beds containing 4 feet 4 inches and 3 feet 4 inches of lignite, separated by 2 feet 3 inches of shale. (See Pl. VII.) To the south this bed thins to 3 feet 4 inches at location 350 and is less valuable at locations 348 and 349, as is shown by the following sections:

Section of lignite beds in the SE. ¼ sec. 16, T. 19 N., R. 7 E.

Location 348.

	Ft.	in.
Shale.		
Lignite		7
Shale, brown		1
Lignite	1	0
Shale, brown		2
Lignite		9
Shale, brown		1
Lignite		8
Shale.		
Total section	3	4
Total lignite	3	0

Location 349.

	Ft.	in.
Shale, brown.		
Lignite		3
Shale, brown	2	11
Lignite, dirty	2	7
Bone		3
Lignite		4
Clay.		
Total section	6	4
Total lignite	3	2

At the foot of the Slim Buttes is the outcrop of a thick series of brown and black shale, with several beds of lignite. This series will be considered as a whole, because the correlation of separate beds is rendered uncertain, not only by the varying character of the beds

themselves but also by the slumping. No lignite is present in the series in sec. 35, but at location 361, in sec. 26, two beds 2 feet 4 inches and 2 feet 1 inch thick are exposed, separated by 2 feet 6 inches of shale. Both beds thicken to the north and the distance between them is less, as shown by sections 362 and 363, Plate VII. At 15 feet below section 363 there is another bed (section 364), containing 3 feet 7 inches of lignite, separated into two benches by 4 inches of shale. At location 366, in the NE. ¼ sec. 23, near the top of a small butte, the lignite is so much weathered that the quality is uncertain, but the bed is at least 4 feet thick. At location 367 (see Pl. VII) several thin beds of lignite interbedded with shale represent the horizon. At location 368, in sec. 24, the following section is exposed in a bed 25 feet below the one just described:

Section of lignite bed at location 368, in the NE. ¼ sec. 24, T. 19 N., R. 7 E.

	Ft.	in.
Shale.		
Lignite, dirty		11
Shale, brown	1	2
Lignite	2	0
Shale.		
Total section	4	1
Total lignite	2	11

Slumping of the younger rocks has been especially common along the north side of the Slim Buttes, and here and there the lignite beds themselves are out of place, so that in sec. 24 the correlation of the different measured sections is uncertain. Sections 369 and 370 (Pl. VII) are supposed to represent the same bed as section 367, and the following section (No. 371) is on the same bed as section 368.

Section of lignite bed at location 371, in the NE. ¼ sec. 24, T. 19 N., R. 7 E.

	Ft.	in.
Shale.		
Lignite, dirty		6
Lignite	1	2
Shale, brown	1	0
Lignite	2	0
Shale.		
Total section	4	8
Total lignite	3	8

A bed of lignite 2 feet 5 inches thick, with a 2-inch shale parting near the top, outcrops high on the side of the mesa, but just below the White River formation, at location 372, in the SE. ¼ sec. 24. This is probably the same bed as that showing at location 335, in T. 18 N., R. 7 E., but the bed does not outcrop elsewhere in T. 19 N., R. 7 E.

T. 20 N., R. 7 E.

The southern part of T. 20 N., R. 7 E., lies in the broad, slightly rolling sandy valley of the South Fork of Grand River. Along the

south side of the river there is a well-defined terrace about 35 feet above water level. North of the river the surface rises gradually to rocky divides capped by level-topped buttes that occupy considerable areas. The high lands are drained by Horse and Coal creeks, which flow southeastward in broad, open valleys.

The Lance is the only formation outcropping in this township. The Ludlow lignitic member of the Lance underlies the divides and the higher land to the north. In general the rocks show a very slight northeasterly dip, but there seems to be a gentle anticline trending north in the northeastern part of the township, which gives in sec. 22 a distinct local northwest dip of more than 3°. Elsewhere the dip does not exceed 100 feet to the mile.

Several beds of lignite, all lenticular, are exposed in this township, but many of them, being but a few inches thick, are not represented on the map. As in many other townships in this field, there is a bed of lignite about 40 feet below the base of the Ludlow lignitic member. It was examined at several places but was mapped only at location 373, in sec. 20, where there is 1 foot of lignite and several feet of brown shale. At the base of the Ludlow member lenses are present at a number of places, but only the two more valuable ones are shown on the map. The one at location 374, in sec. 17, has a total of 2 feet 10 inches of dirty lignite, with a 2-inch sandy parting near the bottom. In sec. 23 the bed was traced for a mile; at location 375 it is 1 foot 4 inches thick, and at location 376, 1 foot 8 inches thick.

At least five beds of lignite crop out in the area occupied by the Ludlow lignitic member. The relation and correlation of these beds are shown in the following table:

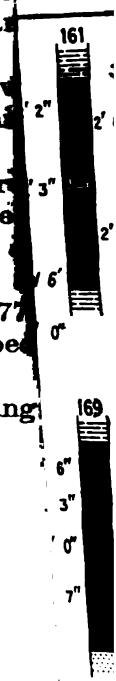
Relation and correlation of lignite beds in the Ludlow lignitic member of the Lance formation in T. 20 N., R. 7 E.

	Feet.
Lignite bed shown in sections 401 and 387, Plate VII, and 389, page 93.	
Interval	10
Lignite bed shown in sections 388 and 390, page 92.	
Interval	40-60
Lignite bed shown in sections 377, 378, 382, 383, 384, 385, 396, 397, 398, and 399, Plate VII, and 381, page 92.	
Interval not known.	
Lignite bed shown in section 391, page 92.	
Interval not known.	
Lignite bed shown in sections 392 and 393, page 92.	
Uncorrelated:	
Section 436, Plate VII.	
Sections 379 and 380, page 93.	
Section 394, page 93.	

Of these beds the highest shows the thickest section (sec. 40 Pl. VII), but the bed underlies only small areas in secs. 4 and 5, a is therefore commercially unimportant.

Ten feet below this thick bed is one which is exposed at only t places. At location 388, in sec. 5, there is less than a foot of ligni and at location 390, in sec. 4, the bed is 2 feet 1 inch thick.

The third bed, 40 to 60 feet lower, underlies a considerable ar and is the only one of value in this township. As shown by the se tions on Plate VII, the bed ranges in thickness from 2 feet 2 inches location 377, in sec. 22, to 6 feet 4 inches at location 399, in sec. At location 381, in sec. 3, the bed is only 2 feet thick. Sections 37 378, 396, 397, and 398 were measured in isolated hills where the be underlies only small areas.



A lower bed at location 391, in the SE. ¼ sec. 4, shows the following section:

Section of lignite bed at location 391, in the SE. ¼ sec. 4, T. 20 N., R. 7 E.

	Ft.	in.
Shale.		
Lignite		7
Shale, brown	1	2
Lignite		10
Lignite, dirty		3
Shale.		
Total section	2	10
Total lignite	1	8

The lowest bed is exposed at locations 392 and 393, where the following sections were measured:

Sections of lignite in secs. 4 and 5, in T. 20 N., R. 7 E.

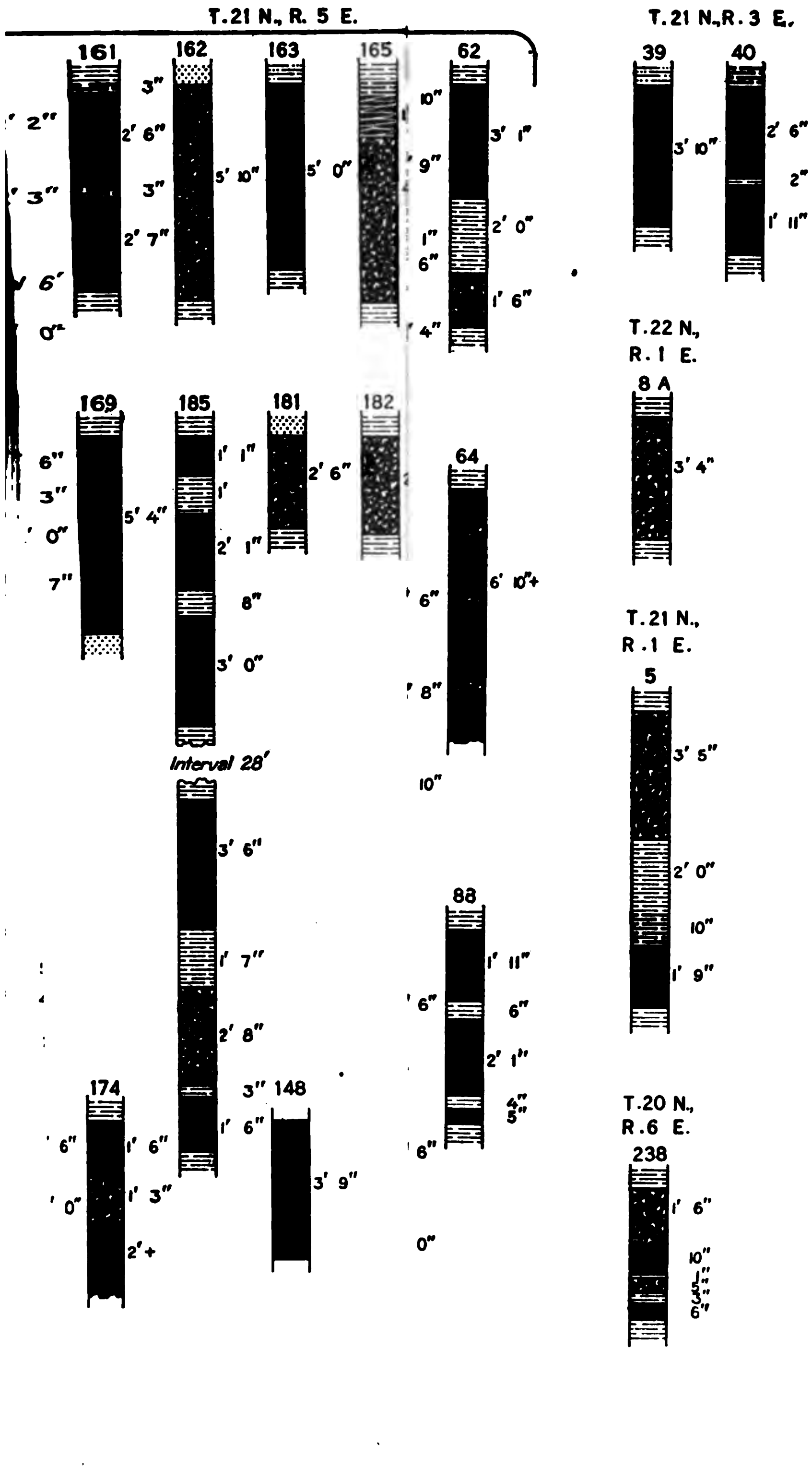
Location 392. Sec. 5.

	Ft.	in.
Shale.		
Lignite, dirty		8
Shale, brown	13	0
Lignite	3	4
Shale.		
Total section	17	0
Total lignite	4	0

Location 393. Sec. 4.

	Ft.	in.
Shale.		
Lignite, dirty	1	1
Clay		1½
Lignite	1	3
Shale.		
Total section	2	5½
Total lignite	2	4

The following sections of beds exposed at four other locations could not be correlated with the beds already described and are therefore treated as isolated exposures and may represent only local lenses:


T. 21 N., R. 5 E.
161
162
163
165
62
169
185
181
182
64
Interval 28'
88
174
148
T. 21 N., R. 3 E.
39
40
T. 22 N., R. 1 E.
8 A
T. 21 N., R. 1 E.
5
T. 20 N., R. 6 E.
238

Sections of uncorrelated lignite beds in T. 20 N., R. 7 E.

Location 379. SE. ¼ sec. 1.

	Ft.	in.
Lignite	2	0

Location 380. NE. ¼ sec. 1.

	Ft.	in.
Shale, brown.		
Lignite		8
Shale		1
Lignite	1	0
Shale	34	0
Lignite		5
Shale		2
Lignite, dirty		6
Shale		2
Lignite, dirty		10
Shale.		
Total section	37	10
Total lignite	3	5

Location 394. Sec. 3.

	Ft.	in.
Lignite, poor		10
Lignite	1	2

Location 436. NE. ¼ sec. 1.

	Ft.	in.
Shale.		
Lignite	3	1
Shale.		

Location 389. NW. ¼ sec. 4.

	Ft.	in.
Shale, brown.		
Lignite, dirty	2	3
Shale, brown	1	6
Lignite		10
Shale.		
Total section	4	7
Total lignite	3	1

T. 21 N., R. 7 E.

The high divide extending southeastward across T. 21 N., R. 7 E., from sec. 19 separates the drainage of Big Nasty Creek from that of the South Fork of Grand River and has an average altitude of about 3,200 feet above sea level. South of the divide the land is deeply dissected into badlands, with many bare slopes and sharp valleys. To the north the country is less broken and is grass-covered. Much of the region is rugged, and level tracts of tillable land are scarce. There are, however, small areas of fairly level land in the east-central part which have been farmed. Springs are numerous in the area and furnish good water for stock; none of the land, however, is so situated that it could be irrigated, except possibly a few small areas along the valley of Big Nasty Creek. Nearly all the middle and northern portions of the township have been filed upon by homesteaders, but the southern two tiers of sections are comparatively unoccupied.

The lowest rocks outcropping in this township are exposed in the valley of Horse Creek, in sec. 34, where the dark argillaceous shale of the lower part of the Lance formation occupies a small area. The greater part of the lower 350 feet of the geologic section is assigned to the Ludlow lignitic member of the Lance formation and consists of sandy and carbonaceous shale, calcareous sandstone, and lignite interbedded. The upper 50 or 100 feet of rocks are assigned to the Fort Union formation. They are very fine grained, sandy, and of light color. Small areas of alluvium occur along the valley of Big Nasty Creek but were not mapped. The strata have a northeastward dip of 15 to 25 feet to the mile. In the southeast corner of the township, in secs. 25 and 26, there seem to be local folds which cause the strata to dip to the northwest.

There is an abundance of lignite in this township. Two important beds and several unimportant beds were mapped. The thinner beds are the lowest and the thicker beds the highest in the geologic section.

The Giannonatti bed is the highest and thickest, having a maximum thickness of 13 feet 6 inches at location 414 (see Pl. VIII), in the northeast corner of sec. 29, and an average thickness in this township of more than 8 feet. Three strip pits have been opened on this bed at locations 415, 416, and 417 near the head of Horse Creek, but the total thickness of the bed is not exposed at any of these places, so that the bed may be much thicker than is shown by the sections. The bed is exposed at locations 406 to 421, 423 to 425, and 435. The bed outcrops along the divide in the southern part of the township and is supposed to be the same as the main lignite bed around the North Cave Hills and the T Cross bed at Ives, N. Dak. The lignite of this bed is good, containing a very little shale and a small amount of marcasite as impurity. All the sections measured on this bed are shown graphically in Plate VIII.

In the vicinity of Two Tops Buttes, in the southeast corner of the township, there is a thin bed of lignite 3 feet 3 inches to 4 feet in thickness (sections 434, 435, and 438, Pl. VIII), 11 feet below the Giannonatti bed.

The Widow Clark lignite bed, so called because it is well exposed (9 feet 6 inches) in the neighborhood of the Clark ranch, at location 442, in sec. 14, is 50 to 70 feet below the Giannonatti bed. Sections 402, 404, 405, 427 to 429, 431 to 433, 437, and 439 to 450 (see Pl. VIII), which are supposed to represent the bed, show a considerable variation in thickness as well as quality of lignite. At location 444, on the east side of sec. 24, the bed is 2 feet 11 inches thick, but at other places along the outcrop in the same valley it shows a much greater thickness. (See sections 440 to 443, Pl. VIII.) A bed at location 437, in the southern part of sec. 36, doubtfully correlated with it, is 3 feet thick. If this is not the same bed, then the Widow Clark lignite is of little value in sec. 36. In the southwest corner of the township measurements on what is supposed to be the Widow Clark lignite range from 3 feet to 8 feet 2 inches (locations 402, 404, 405, 427, 428, 429, 431, 431A, 432, and 433). At locations 446 to 450, on the south side of Big Nasty Creek, there is a lignite bed which is correlated with the Widow Clark bed. At locations 446, 447, and 448, in secs. 3 and 9, it is about 2 feet 10 inches thick, but at location 449, in sec. 8, it is of little value. At location 450, in sec. 6, a carbonaceous zone, which was considered to be at the same horizon, is exposed, but the thickest bed of lignite is only 1 foot 6 inches thick.

The Bond bed outcrops in sec. 4 and contains 2 feet 1 inch of lignite at location 451 and 3 feet 8 inches of lignite, separated into two parts by 10 inches of carbonaceous shale, at location 452.

Along the stream valley in sec. 33 a thin bed of lignite about 3 feet thick is exposed at locations 453 and 454. This bed may be the same as that seen at location 426, in sec. 31, and the lower lignite bed exposed at locations 409 and 405.

A bed of lignite lying between the Widow Clark and Giannonatti bed outcrops at locations 409, 410, 403, and 430, in secs. 31, 32, and 33. It ranges in thickness from 3 feet to 4 feet 2 inches. At location 422, in sec. 8, a bed of lignite above the Giannonatti bed shows 2 feet 2 inches of lignite separated by 3 feet 3 inches of shale from a higher bed of lignite 3 feet thick.

T. 22 N., R. 7 E.

The Tepee Buttes, the most prominent topographic feature in T. 22 N., R. 7 E., consist of several high, pointed hills in secs. 5, 6, 7, and 8. A great number of bowlders from the quartzitic bed of the Fort Union formation cover these hills. The highest point in the township is located in the middle of sec. 7 and has an altitude of 3,266 feet above sea level. Eastward from the Tepee Buttes a rather high, flat divide, with an altitude of about 3,000 feet above sea level, extends across the area and joins the high table-land in T. 22 N., R. 8 E. From this divide the surface slopes southeastward to Big Nasty Creek and northward to the North Fork of Grand River. Away from the Tepee Buttes the surface is roughly rolling and grass-covered, and on the south side of the divide there are several steep hills, capped by rugged ledges of sandstone. The uplands are completely dissected and well drained, and the relief is virtually at a maximum. The larger streams meander widely over the lower portions of their valleys. Big Nasty Creek contains water at nearly all seasons of the year, and always has numerous large pools of water along its course. Its larger tributaries, Williams Creek and Lemmon Creek, are intermittent and flow in a general southeasterly direction.

Nearly the whole of the township has been taken up in homesteads, and many attempts have been made to raise flax, wheat, and corn, but with only partial success. It is probable that the land is better adapted to stock raising than to farming.

As the surface is almost completely grass-covered or cultivated, exposures of rock are very few, consequently a detailed study of the rock formations in this township is very difficult. All the rocks exposed, except those along the divide in the northern part of the township, are assigned to the Ludlow lignitic member of the Lance formation, which consists principally of soft yellowish sandstone, with beds of light-colored sandy shale and lignite. In places the rocks of the Ludlow member show a marked resemblance to those of the overlying Fort Union formation, and the line between the two is therefore an indefinite one. All the lignite beds outcropping in this part of the field belong to the Ludlow. The Fort Union forma-

tion is confined to the northern part of the township, and occupies only the higher areas. It is composed principally of yellow sandstone, but contains some shale, and its total thickness possibly does not exceed 100 feet. A narrow strip of alluvium borders Big Nasty Creek as a thin coating a few feet thick. The beds have a northeasterly dip of less than 25 feet to the mile, as determined by elevations along lignite outcrops. Local minor variations occur in this structure.

Several thin beds of lignite outcrop in the township. The correlation of outcrops on the south and north sides of the divide, in the middle of the township, is nearly impossible, because of the grass-covered surface which conceals nearly all key rocks. In the southern part of the township the Bond bed is the lowest of value. It attains its maximum thickness (see Pl. VIII) at the small mine in sec. 28 (location 457), where there is reported to be more than 7 feet of lignite, though at the time of examination only 3 feet was exposed above water. The bed is 4 feet thick at location 455, in sec. 32, and also at the mine on the Bond ranch (location 456). Sections 455 to 458 and 460, Plate VIII, represent the Bond bed. It ranges in thickness from 1 foot 9 inches at location 462 to more than 7 feet at location 457. At locations 459, 461, and 463, which are assumed to be on the same bed, the thicknesses are 1 foot 3 inches, 1 foot 4 inches, and 1 foot 4 inches, respectively.

At 20 feet below the Bond bed there is a bed showing in a spring at the Bond ranch a thickness of 1 foot 1 inch. About 60 feet above the Bond bed is another exposed at locations 464 to 467. In a small mine at location 465, near the west side of sec. 21, there is 3 feet 8 inches of lignite. At location 466 this bed contains 2 feet 8 inches of dirty lignite, but at locations 467 and 464 the lignite is replaced by carbonaceous shale. Above the bed just described, in the NW. ¼ SW. ¼ sec. 30 and in the NW. ¼ sec. 20, there are two small areas of clinker which are supposed to be on the same bed as that reported to be 3 feet thick in the well in the NW. ¼ sec. 18.

North of the Tepee Buttes there are three beds of minor importance. The bed exposed at locations 468, 470, and 469 is the upper one, its elevation being about 2,950 feet above sea level. It ranges in thickness from 1 foot 3 inches at location 468 to 2 feet at location 469. About 30 feet below this is a bed which at location 471, in sec. 6, is 1 foot 4 inches thick, and in the small mine at location 472 is 1 foot 6 inches thick. The third and lowest bed, which is correlated on the basis of its altitude with the lowest bed in the township to the west, is exposed at location 473, where it is 1 foot 3 inches thick.

T. 23 N., R. 7 E.

The drainage from T. 23 N., R. 7 E., goes into the North Fork of Grand River through small tributaries which flow in a general

northward direction. There are no springs of importance in the township, and the inhabitants are forced to rely on wells as a source of water. The total relief is about 225 feet, one of the highest points being on the State line in sec. 21, where the elevation is 3,010 feet above sea level. Considered as a whole, the township has a rather uneven, rolling surface, with a great number of grassy slopes. The western side of the township is low, but in the middle there is a fairly high, flat upland which is a continuation of the larger plateau-like area to the southeast and is due partly to a cap of somewhat resistant sandstone and thin limestone. In the southwest corner a great number of quartzite bowlders are scattered over the surface and, in a small measure, protect it from erosion and greatly interfere with cultivation. These bowlders originate from a quartzitic bed in the Fort Union formation.

The township has been fairly well settled by homesteaders, who have attempted to grow flax, wheat, and corn, but with only partial success, and it is probable that the region is not suitable for dry farming.

The lower 200 feet of rocks are considered to belong to the Lance formation. In the western portion of the township the lower part of the formation consists chiefly of dark-colored sandy shale, interbedded with a few thin carbonaceous layers and beds of sandstone. The upper part of the Lance is differentiated as the Ludlow lignitic member, because it is slightly different in general character from the underlying beds and contains all the lignite beds in this part of the field. The member contains more light-colored sandstone and more sandy shale than the lower part of the formation and is possibly in part the time equivalent of the Cannonball marine member of the Lance formation farther east. Above the Lance is about 50 feet of yellow sandstone and shale, with interbedded thin limestones, all of which are assigned to the Fort Union formation. Along the bottoms of some of the larger creeks alluvium was found, but the areas are so small that they were not mapped.

No valuable bed of lignite occurs in the township, but several thin ones not shown on the map are exposed. In secs. 32 and 33 there is a small amount of red rock, which is the result of the burning of a thin lignite bed. It is possible that at least part of the township is underlain by good lignite, as beds from 4 to 8 feet thick are exposed in the townships to the east and north.

T. 15 N., R. 8 E.

T. 15 N., R. 8 E., lies in the valley of Moreau River south of the Slim Buttes. The surface is gently rolling and for the most part covered with grass. The lack of sufficient rainfall or surface water in this part of the field has prevented settlement, except by a few

sheep ranchers. The soft somber-colored shale of the Lance formation constitutes the surface rock of that part of the township north of the river and is not lignite-bearing. On one of the low terraces along Moreau River, in the southern part of the township, there are numerous areas covered by subangular bowlders of hard gray quartzite similar to those scattered over the surface in many other parts of the field.

T. 16 N., R. 8 E.

The Slim Buttes, in the northern half of T. 16 N., R. 8 E., stand out as a high mesa 500 feet above the surrounding country. The south face of the buttes (Pl. IV, *B*, p. 32) is little dissected but rises as an almost impassable wall, extending in an easterly direction across the township. Along the east face, however, several small streams have cut into the cliff, producing narrow, steep-walled canyons. Immediately south of the buttes the surface is deeply dissected and exposures of rock are numerous, but the bedrock structure is greatly obscured by landslides. The southern part of the township is gently undulating and is covered with grass, so that exposures of rock are scarce. Numerous small farms have been established along the southern edge of the area, but the scarcity of water is proving a great hindrance to the raising of crops. Several good springs along the margin of the buttes have been utilized by the ranchmen, who years ago located where water was most accessible.

The lower part of the Lance formation, which contains no lignite, except near the top, is exposed in the area south of the Slim Buttes, where it weathers to sandy soil. The Ludlow lignitic member of the formation is represented by less than 50 feet of yellow sandy shale and sandstone outcropping at the base of the buttes. The White River and Arikaree (?) formations, which form the Slim Buttes, consist of about 200 feet of white clay, marl, sandstone, and conglomerate and overlie the lignite-bearing rocks unconformably. The rocks of the Lance dip gently to the northeast.

Several exposures of lignite were found near the top of the lower part of the Lance formation, which are interpreted as belonging to the same bed. At locations 475, 476, 477, and 478 the bed shows a thickness of good lignite ranging from 2 feet 6 inches (location 478) to 5 feet (location 476). The sections of the bed at these places are shown on Plate XI. No mining or prospecting has been done in the township.

T. 17 N., R. 8 E.

The surface of T. 17 N., R. 8 E., is varied. In the central and western parts the flat-topped J–B Hill and the Slim Buttes rise 300 to 400 feet above the surrounding area and stand out in marked contrast to the gently undulating grass-covered plain which is char-

acteristic of the Big Meadow to the east. The almost perpendicular cliff along the edge of the Slim Buttes mesa is deeply incised by numerous steep-sided canyons, so that the eastern margin of the mesa appears as a very irregular, almost impassable wall. A scanty growth of pine and cedar trees clothes the mesa and forms a valuable asset of the country.

Numerous small springs of good water issue from the sandstone near the base of the buttes and have been utilized by the few ranchers in the region. Very little farming has been done in this township, probably because of the roughness of the surface.

Along the margin of the buttes rock exposures are numerous, but owing to the great amount of slumping it is difficult to determine whether or not a bed is in its original position. The Lance, White River, and Arikaree (?) formations are all exposed in this township. The somber-colored shale of the lower part of the Lance formation occupies a small area along Antelope Creek, in the southeast corner of the township, and contains at one locality (location 479, sec. 25) a 3-foot bed of poor lignite. The Ludlow lignitic member of the Lance is composed of yellow shale, with soft yellow sandstone, some carbonaceous shale, and lenticular beds of fair-grade lignite. Unconformably above the Lance and forming the Slim Buttes and J. B. Hill is a series of white, light-gray, and pink clay, marl, and sandstone, which contains no lignite and is in places highly cross-bedded. The lower part is known to be of White River (Oligocene) age. The upper part is assigned to the Arikaree (?) sandstone because of its lithologic similarity to the Arikaree sandstone of southern South Dakota. The strata of the Lance formation in this part of the field dip gently northeastward.

The only two valuable lignite beds that are known to crop out in the township occur in the upper part of the Lance formation. The upper bed was measured at locations 494, 494B, and 495 to 501 and attains its maximum thickness of 6 feet at a small strip pit in sec. 8 (sec. 498, Pl. XI). All the sections obtained at the locations mentioned are shown graphically on Plate XI except that at location 501, which is as follows:

Section of lignite bed at location 501, in the SW. ¼ sec. 5, T. 17 N., R. 8 E.

	Ft.	in.
Lignite, weathered, full thickness not determined	1	9+
Shale, brown		1
Lignite		9
Shale, brown.		
Total section	2	7+
Total lignite	2	6+

The lower bed, about 30 feet below the one described above, is exposed at locations 502, 503, and 504 and has been mined for local use at location 503, in sec. 5. The sections measured at these places

(represented graphically on Pl. XI) show a variation in thickness from 2 feet 11 inches to over 4 feet 8 inches. At location 503 another bed 1 foot 8 inches thick is exposed 12 feet below the main bed. The two strip mines (locations 503 and 498) have been operated unsystematically by the ranchers near by to supply their own needs.

At many places in the township (see map, Pl. I) the lignite beds have burned along their outcrop, baking the overlying rocks to red scoria or clinker.

Several thin beds of lignite are exposed at various places in the township, but their stratigraphic relations to one another and to the thicker beds were not determined. The following measurements show their character and thickness:

Section of thin lignite beds in the Ludlow lignitic member of the Lance formation exposed in T. 17 N., R. 8 E.

[Not shown on Pl. XI.]

No. on Pl. I.	Location.	Section.	Ft.	in.
480	NE. ¼ sec. 28..	Shale, light brown, sandy.	12	0
		Shale, brown......		8
		Lignite........		½
		Shale, brown..		6
		Lignite........	1	8
		Shale, brown.		
		Total section	14	10½
		Total lignite.	1	8½
481	SW. ¼ sec. 21..	Shale, brown......	1	5
		Lignite........	1	8
		Shale, brown.		
		Total section	3	1
		Total lignite.	1	8
482	SW. ¼ sec. 21..	Shale, light brown.	8	0
		Shale, brown......		4
		Lignite........	2	3
		Shale, brown.		
		Total section	10	7
		Total lignite.	2	3
483	SE. ¼ sec. 21...	Clay, sandy.		
		Shale, brown......		4
		Lignite........	1	5
		Shale, brown.		
		Total section	1	9
		Total lignite.	1	5
484	NW. ¼ sec. 22..	Soil............. ..		8
		Lignite........	1	4
		Shale, light brown, clayey.		
		Total section	2	0
		Total lignite.	1	4
485	SW. ¼ sec. 22..	Clay, sandy.		
		Lignite........	2	0
		Shale, brown.		
486	SW. ¼ sec. 22..	Clay, sandy.		
		Lignite........	1	2
		Shale, brown.		
487	SW. ¼ sec. 22..	Clay, sandy.		
		Lignite........	2	0
		Shale, brown.		
488	SW. ¼ sec. 14..	Shale, reddish brown, sandy; some gravel.	1	0
		Lignite........	1	8
		Shale, brown.		
		Total section	2	8
		Total lignite.	1	8
489	NW. ¼ sec. 14..	Shale, light brown, sandy, and clay.	4	6
		Shale, brown......	2	4
		Lignite........	1	2
		Shale, brown.		
		Total section	8	0
		Total lignite.	1	2
490	NW. ¼ sec. 14..	Shale, light, sandy.	2	6
		Lignite........		8
		Interval...........	7	0
		Lignite........	2	0
		Shale, brown.		
		Total section	12	2
		Total lignite.	2	8
491	NE. ¼ sec. 17..	Shale, brown......		4
		Lignite........	1	9
		Shale, brown.		
		Total section	2	1
		Total lignite.	1	9
492	SE. ¼ sec. 10...	Clay, sandy.		
		Lignite........	1	6
		Shale, brown.		
493	SE. ¼ sec. 10...	Clay, sandy.		
		Shale, brown......		6
		Lignite........	2	4
		Shale, brown.		
		Total section	2	10
		Total lignite.	2	4
494 A	SW. ¼ sec. 16..	Clay, sandy.		
		Shale, brown......		6
		Lignite........	1	6
		Shale, brown.		
		Total section	2	0
		Total lignite.	1	6

Of these sections, 480, 481, and 482 are supposed to be on one bed, 485, 486, and 487 on another, and 489 and 490 on a third.

T. 18 N., R. 8 E.

T. 18 N., R. 8 E., lies at the west margin of the Big Meadow and includes a portion of the Slim Buttes, which rise abruptly 300 feet or more above the surrounding plain. Around these buttes the surface is gently rolling, although close to the cliff line streams have dissected the area until at places it is almost impassable. In the eastern half of the township the surface is gently rolling and grass covered, and numerous small farms have been established in the last few years. Large springs of excellent water issue from rocks near the base of the buttes and have been used by the ranchers of the region as watering places for large herds of cattle and horses. Among these, the spring at the old L ranch in sec. 28 is probably the best known.

The lower portion of the Lance formation is exposed in a small area in sec. 18, in the valley of Sioux Creek west of the Slim Buttes. Above and almost inseparable from these beds is the Ludlow lignitic member of the Lance, which is composed of yellow sandy shale and soft sandstone, with some carbonaceous shale and lignite. In the Slim Buttes it is overlain unconformably by the White River formation and this, in turn, by the Arikaree (?) sandstone, neither of which is lignite-bearing. These formations include more than 300 feet of light-colored clay, marl, sandstone, and conglomerate, and the lower part is in places markedly cross-bedded. Cross-bedding is especially conspicuous in Reva Gap, in sec. 17, and south of the old L ranch, in sec. 32.

Along the east side of the buttes rock slumps and landslides have rendered the interpretation of the structure and the correlation of the lignite beds very difficult. The Lance and the underlying formations, however, appear to dip to the northeast at angles ranging from about 15 feet to the mile in the western part of the township to 35 feet to the mile in the eastern part.

East of the Slim Buttes, in the southern part of the township, two beds of lignite reach a thickness of 3 feet or more at several places along their outcrops. The upper bed, illustrated by sections 505 to 510, Plate XI, attains a maximum thickness of 4 feet 11 inches at location 508, in sec. 28, where near-by ranchers have mined lignite for their own use. The same bed at location 511, only a short distance to the northeast of location 510, is less valuable, as shown by the following section:

Section of lignite bed at location 511, in the SW. ¼ sec. 21, T. 18 N., R. 8 E.

	Ft.	in.
Shale, drab.		
Lignite		8
Shale, brown		2
Lignite	1	1
Shale, brown.		
Total section	1	11
Total lignite	1	9

The second bed, 25 feet lower, is represented by sections 516 to 519, Plate XI, and ranges in thickness from 2 feet 6 inches at location 519 to 6 feet 10 inches at location 516. This bed has not been mined. Lignite beds more than 2 feet 10 inches thick are exposed at locations 515 and 520, but the extent of the beds beyond the exposures is not known. A lignite bed more than 2 feet in thickness has been stripped at location 521, in sec. 22, and several wagon loads of fuel have been removed, but probably there is no great area of lignite here, as the rocks in this vicinity are much disturbed and the lignite bed is probably included in a landslide.

In the northern part of the township three beds of lignite attain a thickness of more than 2 feet 10 inches. The upper one, along its outcrop, increases in thickness from 2 feet 6 inches at location 525, in sec. 16, to 6 feet at location 526, in sec. 17, and then diminishes to 2 feet 1 inch at location 527, also in sec. 17. About 10 feet below this bed, in sec. 8, a second bed (represented by sections 530 and 531, Pl. XI) has been mined on a small scale at location 531, where it is 4 feet 6 inches thick. A third bed, about 40 feet below the second, is exposed at locations 528 and 529. At location 528, in sec. 8, it has been mined on a small scale and is more than 9 feet thick. At location 529, in sec. 4, a bed supposed to be at the same horizon has a thickness of at least 5 feet.

In addition to the sections shown graphically on Plate XI the following represent thin, nonpersistent lignite beds that are exposed in T. 18 N., R. 8 E., east of the Slim Buttes.

Sections of thin lignite beds exposed on the east side of Slim Buttes in T. 18 N., R. 8 E.

[Not shown on Pl. XI.]

No. on Pl. I.	Location.	Section	Ft.	in.
512	SW. ¼ sec. 33..	Shale, brown.		
		Lignite..........	1	6
		Shale, brown....		4
		Lignite..........		11
		Shale, brown		
		Total section..	2	9
		Total lignite...	2	5
513	NE. ¼ sec. 33..	Shale, brown........	1	3
		Lignite..........	2	6
		Shale, brown.		
		Total section..	3	9
		Total lignite...	2	6
522	NW. ¼ sec. 23..	Clay, sandy.		
		Lignite..........		10
		Shale, brown....	1	5
		Lignite..........		8
		Shale, brown.		
		Total section..	2	11
		Total lignite...	1	6
523	SW. ¼ sec. 15..	Lignite..........	1	6
		Shale, light, sandy	1	2
		Lignite..........	2	0
		Shale, brown.		
		Total section..	4	8
		Total lignite...	3	6
524	SW. ¼ sec. 15...	Shale, light, sandy.		
		Lignite..........	1	9
		Shale, brown.		
532	SE. ¼ sec. 9....	Sandstone, brown...	2	0
		Lignite..........	2	0
		Shale.		
		Total section..	4	0
		Total lignite...	2	0
533	NW. ¼ sec. 11..	Shale, brown.		
		Lignite..........	2	3
		Shale, brown.		

On the west side of the Slim Buttes lignite beds ranging in thickness from 4 feet at location 537 to 2 feet 6 inches at location 538 are

exposed at a number of places. Sections 534 to 541, 543, shown on Plate XI, give an idea of their thickness and character. At location 542 the following section is exposed:

Section of lignite bed at location 542, sec. 28, T. 18 N., R. 8 E.

	Ft.	in.
Shale.		
Lignite		4
Shale	1	9
Lignite		5
Shale		10
Lignite	1	3
Shale.		
Total section	4	7
Total lignite	2	0

One small mine has been opened at location 535, in sec. 20, but only a lew loads of lignite have been removed.

T. 19 N., R. 8 E.

The surface of T. 19 N., R. 8 E., is exceedingly rough and shows a maximum difference in altitude of 700 feet. The flat-topped mesa of the Slim Buttes, which occupies the southwest corner of the township, terminates in a steep, almost impassable cliff more than 200 feet high. Between this cliff and the open valley of the South Fork of Grand River, at the northern boundary of the township, the surface is deeply dissected into numerous narrow, rugged coulees. Dark-red scoria resulting from the burning of lignite appears in marked contrast to the nearly pure white clay and sandstone of the White River and Arikaree (?) formations, and where slumping has brought the two into contact the contrast is especially striking. With the exception of a small area in secs. 35 and 36, this township is too rough to be used for farming.

The somber-colored shale of the lower part of the Lance formation crops out in the small valleys in the northern part of the township. It is overlain by the Ludlow lignitic member of the Lance, which is composed of about 165 feet of yellow sandstone, yellow shale, carbonaceous shale, and lignite. The White River and Arikaree (?) formations constitute the Slim Buttes and rest unconformably on the Ludlow member. The White River, about 60 feet thick, is composed of white and light-colored clay and thin beds of sandstone, and the Arikaree (?), about 180 feet thick, is composed of soft white tuffaceous sandstone with some conglomerate.

Rock exposures are numerous in the area north of the Slim Buttes, but landslides have so greatly disturbed the surface rock that it is almost impossible to correlate lignite beds or correctly interpret geologic structure. One of the most noticeable landslides in the field is in sec. 20, where a block of White River beds half a mile long, 500

feet wide, and about 125 feet thick, has moved down laterally until now it occupies the bottom of a valley where it is surrounded by rocks of the Lance formation. (See Pl. III, *B*, p. 10.) Many less extensive landslides, affecting not only the White River but also the lignite-bearing formation of the field, have occurred in the township. The lower rocks dip eastward about 70 feet to the mile in the western part of the township, but the dip decreases to about 10 feet to the mile in the eastern part.

Only a few settlers live in the vicinity, and therefore the demand for lignite is small. The Bar H mine, which is the only one that has been opened in the township, is in sec. 27 (location 544). A wagon road has been constructed to this mine, and considerable fuel has been removed by stripping.

The most valuable lignite bed and the only one whose outcrop can be followed with a fair degree of certainty is exposed at the base of the Slim Buttes, only a few feet beneath the White River formation, and may have been destroyed locally by erosion before the deposition of the younger formation. The thickness at locations 544, 545, and 547 to 550 along its outcrop varies from 3 feet 5 inches at location 550, in sec. 19 (see Pl. XI), to 13 feet 8 inches at location 544, in sec. 27.

Thick beds of lignite are exposed at a number of places in the township, measurements of which are shown graphically on Plate XI. Sections 563 to 570 were measured along the outcrop of a bed near the base of the Slim Buttes that ranges in thickness from 2 feet 2 inches at location 563 to 6 feet 1½ inches at location 564. The bed at the base of the Ludlow lignitic member of the Lance (locations 572 to 575) is of little value in this township. Even though it reaches a maximum thickness of 3 feet 2 inches at location 574 (Pl. XI), it is so thin at every other place where it was seen that it can not be considered of commercial importance. The exact correlation of lignite beds in most other parts of the township is impossible. Sections 557 and 558 are supposed to belong to one bed, sections 559 and 560 to another, 576 and 577 to another, and 578 and 579 to still another. Sections 546, 551 to 555, 561 and 562 (Pl. XI) represent lignite beds having a thickness of more than 2 feet 10 inches, but on account of poor exposures the outcrops could not be connected or the beds correlated. The following sections of thin beds were made at places indicated on the map (Pl. I):

Sections of thin lignite beds in T. 19 N., R. 8 E.

[Not shown on Pl. XI.]

No. on Pl. I.	Location.	Section.	Ft.	in.
556	NE. ¼ sec. 22..	Shale, brown.		
		Lignite..........	1	7
		Shale, brown.		
571	SW. ¼ sec. 18..	Shale, brown.		
		Lignite, dirty....		8
		Shale, brown.........	3	2
		Lignite..........		6
		Lignite, dirty....	1	9
		Shale, brown.		
		Total section..	6	1
		Total lignite...	2	11
572	NW. ¼ sec. 7...	Shale, brown.		
		Shale, carbonaceous.		4
		Shale................		3
		Lignite..........		4
		Shale, brown....		4
		Lignite..........	2	8
		Shale, brown.		
		Total section...	3	11
		Total lignite...	3	0
578	NE. ¼ sec. 10..	Shale, brown.		
		Lignite..........	2	5
		Shale, brown.		
579	NW. ¼ sec. 15..	Shale, brown.		
		Lignite..........		7
		Shale, brown....		3
		Lignite..........	2	3
		Shale, brown.		
		Total section..	3	1
		Total lignite...	2	10

T. 20 N., R. 8 E.

T. 20 N., R. 8 E., drains into the South Fork of Grand River, which meanders through the southern part of the township in an open valley. After heavy showers and during the spring thaws the river becomes a torrential stream, owing to the very rapid run-off of the water. Skull Creek drains the northwest corner of the township, Brushy Creek the middle, and Horse Creek the western part. These three intermittent streams flow in a general southeasterly direction, which is roughly parallel to the strike of the rocks. The maximum difference in altitude in this area is about 600 feet, the highest points, almost 3,200 feet above sea level, being near the northwest corner, in secs. 4 and 5. The surface of the township is very rough and is not suitable for cultivation. Narrow, high rocky divides separate the small streams that cross the township and almost prevent travel from one valley to the adjoining one. Although a number of homesteaders have recently taken up claims in different parts of the area, little successful farming is to be expected, even with dry-farming methods, except in a few small areas along the larger streams. Most of the land along the South Fork of Grand River is too sandy to make good farm land, and although the river is a perennial stream, only a very small amount of water is available for irrigation, especially during the season when it is most needed.

A few old ranches are situated in the more favorable localities, and the area will probably continue to be used as grazing land for cattle and horses. Bratsburg post office is in sec. 8.

About 600 feet of strata are exposed in this township. They belong almost entirely to the Lance formation, although there may be a small

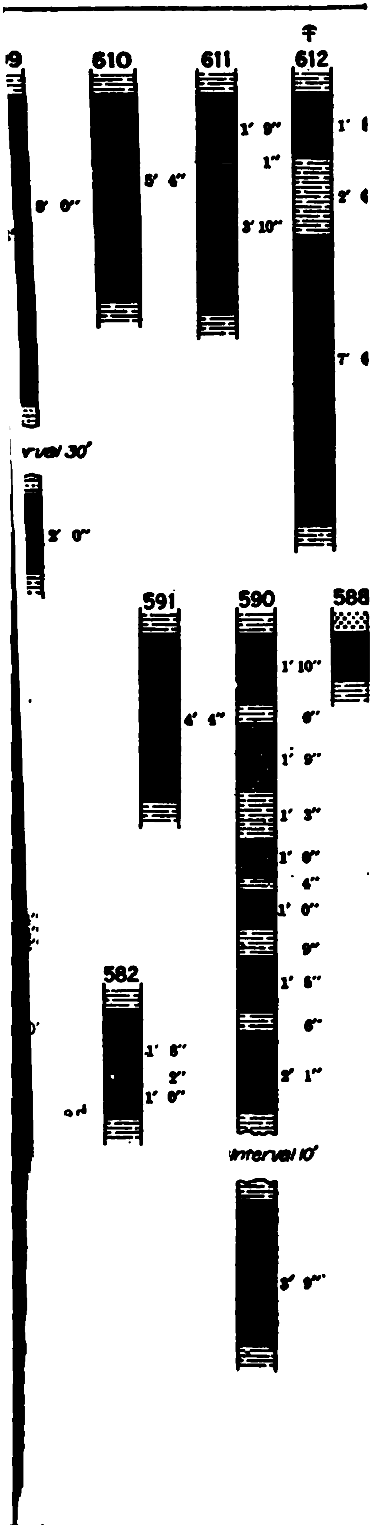
thickness of Fort Union rocks on the highest points in the northwe corner. The lithologic difference between the two formations is slight that in a grass-covered area it is impossible to separate the The lower part of the Lance formation is present in the valley of t South Fork of Grand River, but alluvium and sand obscure the roc so that a study of their character is difficult. Immediately belo the lowest lignite bed, which is assumed to be the base of the Ludlo lignitic member, the formation is composed of dark-colored clay sha with a few lenses of sandstone and beds of carbonaceous shale. The are in places much cross-bedded. Above this lignite bed the roc are more sandy and light colored and contain numerous lignite bed one of which outcrops along the ridges in this and adjacent townshi and has been mined at a number of localities. The dip is northeast probably not more than 20 feet to the mile, as determined by altitudes on the main lignite bed.

There are at least four lignite beds worthy of note in this township; two of them are of good thickness and quality, but the other two are of questionable commercial value. The lowest bed outcrops along the north side of the South Fork of Grand River at locations 580, 581, 583 to 588, 590, and 591 (see Pl. VIII) and is of little worth; in fact, at locations 581,.583, 586, and 588 it is not much more than carbonaceous shale.

Along the stream bank at locations 585 and 587, in sec. 27, the bed is more than 3 feet thick, and at location 580, in sec. 29, it is 4 feet 6 inches thick. A local lens of lignite above the lowest bed has a thickness of 2 feet 10 inches at location 582, in sec. 21, but is not exposed elsewhere.

Along Skull Creek near the Henry ranch, in sec. 11, is the outcrop of a lignite bed nearly 200 feet above the one just mentioned, which ranges in thickness from 2 feet at location 623, in sec. 24, to 3 feet at location 620, in sec. 11. (See sections 620, 620A, 623, 624, and 625, Pl. VIII.) Beds exposed at locations 589, 606, 607, and 614 are supposed to represent the same bed. Of these the bed exposed at location 606 is the thickest, measuring 4 feet 6 inches. The bed has been worked locally at a small opening (location 620) about half a mile above the Henry ranch.

Nearly 100 feet above the second bed is another, represented by sections 592 to 605, 608 to 613, 615 to 619, and 621 to 622B, Plate VIII, which is supposed to be the same as the Widow Clark lignite of T. 21 N., R. 7 E. Its thickness ranges from about 2 feet at location 622B, in sec. 12, to 9 feet at location 608, in sec. 23. At most places along the outcrop the bed contains more than 4 feet of good lignite. Three small strip pits have been opened on it—one at location 622, in sec. 1; another at location 612, in sec. 9; and a third at location 604, in sec. 22. The lignite is of about the same quality as the sample



610
611
612
8' 0"
5' 4"
1' 9"
1"
3' 10"
591
590
588
4' 4"
1' 10"
6"
1' 9"
1' 3"
1' 6"
4"
1' 0"
9"
1' 8"
6"
2' 1"
582
1' 8"
2"
1' 0"
interval 10'
3' 9"
2' 0"

to

taken from this bed at the Newcomb mine, in T. 20 N., R. 9 E., which shows about 12 per cent of ash and a heating value of 8,520 British thermal units in an air-dried sample. About 100 feet above the Widow Clark lignite bed is the one locally called the Giannonatti bed, which is well exposed in T. 21 N., R. 7 E. This bed at the east side of sec. 9 of this township (location 612A) contains 8 feet of good lignite. The bed has been burned at several places, giving rise to large masses of red fused rock, particularly in secs. 1, 4, 9, 16, and 22. In secs. 22 and 16 large masses of baked rock cap the divide and may be seen for several miles, standing out like high red signals. The bed underlies small areas in secs. 1, 4, 5, 8, and 9, but in adjacent areas in both North and South Dakota, the bed averages about 5 feet in thickness and underlies large areas.

T. 21 N., R. 8 E.

T. 21 N., R. 8 E., for the most part drains almost directly into Big Nasty Creek, which flows southeastward across the township from the northwest corner in a broad, open valley. The southern part of the township drains into Skull Creek. Through the southern part extends a high dissected ridge, locally known as the Circle Hills, with altitudes ranging from 3,000 to 3,200 feet above sea level. The surface of the rest of the township is uneven but grass-covered, so that rock exposures are scarce.

Although the surface of the township is very rough, it is fairly well settled. At Ralph, a small settlement at the old Howard ranch, in sec. 24, there is a combination store and post office. As a whole the township seems better adapted to grazing than to dry farming, because most of it is too hilly to be conveniently cultivated. The narrow strip of bottom land along Big Nasty Creek may possibly be farmed by irrigation, but the supply of water is meager, for in dry times the creek does not contain running water. Farmers depend largely on wells for water, and what they get is mostly alkaline.

Of the 500 feet of rocks exposed in this township the lower 300 feet belong to the Ludlow lignitic member of the Lance formation, and the upper 200 feet is assigned to the Fort Union formation. The Lance in this township is composed of dark-colored, sandy and carbonaceous shale, coarse-grained, brownish to gray sandstone, and lignite. South of Big Nasty Creek, near the center of the township, one of the indurated sandstones forms the top of a prominent ridge. The sandstone has been used for buildings.

The Fort Union formation, which is present on the upland in the northeast corner of the township and in a high hill in sec. 31, is composed of light-colored sandstone with a few thin beds of shale. No lignite is known in the formation in this part of the field, but to the north and east the Fort Union contains some of the best lignites of the Dakotas.

Along the valley of Big Nasty Creek there is considerable alluvium derived from the rocks of the surrounding country.

The rock strata in this township are very nearly horizontal, but the altitudes determined on the Widow Clark lignite in the valley of Big Nasty Creek indicate a slight but regular dip to the northeast.

Several beds of lignite are exposed in the township. The lowest one mapped is the Widow Clark lignite, which is exposed at a number of places and has been worked at three small strip mines. Although the mantle of grass and soil obscures the outcrop of lignite beds and makes the correlation of exposures very difficult, the beds at locations 631 to 633, 647, 650 to 653, 655 to 657B, and 661 to 674 are supposed to represent the Widow Clark lignite in this township. The bed varies greatly in thickness from place to place, as will be seen by reference to the graphic sections on Plate IX. The maximum thickness measured is at location 667, in sec. 6, where the bed is 8 feet thick and the upper part is poor lignite. Several wagon loads of fuel have been mined by stripping from each of the small mines at locations 632, 653, and 667.

About 20 feet above the Widow Clark is the Bell bed. Measurements at locations 644, 645, 646, 648, 649, 654, 658, and 659, shown graphically in Plate IX, are probably on this lignite bed, although absolute correlation is impossible. The bed ranges in thickness from 10 inches at location 646, in the center of sec. 26, to 5 feet at the Bell mine at location 648, in the NE. ¼ sec. 27. At location 645, in the SW. ¼ sec. 25, there is a second prospect. The quality of the lignite in this bed is fair.

About 22 feet above the Bell bed occurs a third, along the outcrop of which sections 634, 635, 636, 638, and 639 were measured. Its thickness ranges from 1 foot 6 inches at location 634 to more than 4 feet at location 639. West of location 634 the bed is of little value and was not mapped.

About 70 feet above the Bell bed is the Giannonatti bed, which is exposed at locations 630, 637, 629A, 629B, 628, 627, and 641. At location 637 the bed is only 2 feet 4 inches thick, but elsewhere it is much thicker, as is shown graphically by the sections on Plate IX, and is thickest at the Shirley mine (location 629B), in sec. 35, where the following section is exposed:

Section of lignite bed at Shirley mine, sec. 35, T. 21 N., R. 8 E.

	Ft.	In.
Shale.		
Lignite	7	10
Shale		10
Lignite	5	9
Sandstone.		
Total section	14	5
Total lignite	13	7

Considerable lignite has been taken from this mine for local use. The lignite encountered at a considerable depth in a well located in sec. 1 and reported to be about 6 feet thick may be this bed or possibly the Widow Clark bed.

T. 22 N., R. 8 E.

The most marked surface features of T. 22 N., R. 8 E., are the Lodgepole Buttes, in the extreme eastern part. These buttes form the culmination of the divide that stretches westward and separates the drainage, part of which flows southward by small tributaries into Big Nasty Creek and the remainder by small tributaries into the North Fork of Grand River. The divide is a part of the more or less extensive table-land that surrounds the Lodgepole Buttes. The altitude of the highest butte is 3,222 feet above the sea level, or about 200 feet above the general level of the surrounding country. The surface of the township is for the most part broken and grass-covered, but here and there, as along the south and north sides, deep valleys are encroaching on the upland area. Nearly all the land has been taken up in homesteads, but only ordinary crops of grain have been raised. The land produces an abundance of natural grass that furnishes excellent grazing, and stock raising so far is the most profitable industry.

The Lance formation, consisting of interbedded shale, sandstone, and lignite, is exposed in the Cadyville Valley, in the northern part of the township, and south of the divide in the southwest corner. In the Cadyville Valley and in sec. 2 part of the strata are assigned to the Cannonball marine member of the Lance; the remaining portion of the Lance is referred to the Ludlow lignitic member because it contains lignite beds. The upper 300 feet of beds exposed, consisting of shale, sandstone, and limestone, somewhat lighter colored than those of the Lance, belong to the Fort Union formation. The upper part of the Fort Union is a brown massive, somewhat coarse-grained sandstone. This phase of the Fort Union is well developed in the cap of the Lodgepole Buttes. Here and there along the west slope of the buttes are quartzite bowlders that have been derived from the quartzitic stratum in the Fort Union.

Two lignite beds were mapped in this township. The lower and thinner one outcrops in secs. 33, 34, and 35, and the only data regarding its thickness were obtained from the wells at locations 676 and 677, where it is reported as 2 feet 9 inches and 2 feet 4 inches thick, respectively. It is also reported as 4 feet thick in a well at location 675, in the NW. ¼ sec. 3 of the township immediately to the south. The sections of this bed are shown graphically on Plate IX. A thick bed of fair quality, supposed to be the same as the Giannonatti bed in T. 21 N., R. 7 E., is separated from the thin bed by about 30 feet of shale and sandstone. The bed has an average thickness of about

6 feet, ranging from 3 feet 8 inches at location 680, in sec. 29, to 12 feet (well record) at location 678, in the SW. ¼ sec. 27. It is mined on a small scale at location 684, near the center of sec. 9. The sections of the lignite bed at locations 678, 678A, 680, 681, 683, 684, 685, and 686 are shown graphically on Plate IX. There is some doubt whether the bed at an average altitude of 2,850 feet at locations 683, 684, 685, and 686, in the northwest corner of the township, is the same as the one on the south side of the divide, which occurs at an altitude of 2,840 to 2,865 feet, but if it is, the formations and lignite beds in this township lie nearly flat. The 3 feet of lignite reported to have been struck at a depth of 40 feet in a well at location 679, in the southwest corner of sec. 28, may possibly be on this bed, as is the 6 feet of lignite reported in the well 40 feet deep at location 681, in the NW. ¼ sec. 32. A third bed of lignite may underlie the Lodgepole Buttes, for in the township to the east such a bed has been prospected at two localities and is 4 feet thick.

T. 23 N., R. 8 E.

The surface of T. 23 N., R. 8 E., as a whole, is gently rolling, but exhibits a few rather steep slopes, which are due to resistant beds of sandstone and limestone. It may be described as a region in physiographic maturity, the uplands being completely dissected and well drained and the larger streams meandering on their flood plains. The drainage goes entirely into the North Fork of Grand River. The total relief is about 200 feet. About nine-tenths of the township may be classed as upland, and the rest as bottom land. The land seems to be pretty well suited to dry farming, and fair crops of flax and wheat are grown. There are many tracts of grassy land, and only one-quarter to one-half of the arable land has been broken. The small village of Cadyville is situated in the SE. ¼ sec. 32.

The oldest rocks exposed in this township are classified as the Ludlow lignitic member of the Lance formation. They are composed chiefly of dark, sandy shale and sandstone interbedded and contain one fairly good bed of lignite at the top. The total exposed thickness of this member is about 50 to 75 feet. The strata outcrop along the sides of the Cadyville Valley and along the valley in which the stage line runs from Haley, N. Dak., to Ralph, S. Dak., and occupy the greater part of the lowlands.

Between the Ludlow lignitic member of the Lance and the Fort Union formation, along the North Fork of Grand River and its tributaries, there is a series of rocks containing marine fossils, which is assigned to the Cannonball marine member of the Lance. No fossils were found in the member in this township, but near Bloom, in the township to the east and across the State line in North Dakota, marine fossils were found above the lignite bed. The rocks of the

Ludlow lignitic member and those of the Cannonball marine member are very similar lithologically, but the former contain lignite and other evidences of fresh-water deposition, whereas the latter contain marine fossils.

The Fort Union formation, which consists of sandstone and shale, covers a large portion of the township, including all the upland. Some of the sandstone beds are more resistant than others and cause the more or less abrupt breaks at the edge of the uplands. About 100 feet of the formation is present.

A deposit of alluvium about half a mile wide and 3 miles long occurs along the large creek leading from Cadyville to Haley.

For economic and stratigraphic purposes the strata of this township may be considered horizontal, but they have a very slight northeasterly dip, as determined by altitudes on the lignite bed traced from T. 22 N., R. 8 E., through T. 23 N., R. 8 E., to the State line, the dip of the bed apparently being just about the same as the gradient of the larger stream.

One bed of lignite is exposed at two or three places in this area; elsewhere its outcrop is concealed by soil and grass. At location 682 (see Pl. IX) in the SW. ¼ SE. ¼ sec. 21, the following section was measured:

Section of lignite bed at location 682, in the SW. ¼ SE. ¼ sec. 21, T. 23 N., R. 8 E.

	Ft.	in.
Shale.		
Lignite, dirty		4
Lignite	1	8
Shale		8
Lignite	1	8
Total section	4	4
Total lignite	3	8

Across the creek, at location 687, in sec. 28, there is a lignite bed exposed at about the same altitude, which has the following section:

Section of lignite bed at location 687, in sec. 28, T. 23 N., R. 8. E.

	Ft.	in.
Shale.		
Lignite	1	0
Shale		½
Lignite		11
Shale	3	0
Lignite		10
Total section	5	9½
Total lignite	2	9

In the township to the south the bed ranges from 2 feet 6 inches to about 7 feet in thickness. It is reported that a well in the NW. ¼ NE. ¼ sec. 26 struck at least 4 feet of good hard lignite, which may

represent the same bed. Although correlation of this bed with those exposed in neighboring townships is impossible, it is thought to be the same as the Giannonatti bed.

T. 15 N., R. 9 E.

T. 15 N., R. 9 E., is south of the east end of the Slim Buttes and includes Sheep Mountain, a high isolated butte which rises to an altitude of about 3,400 feet above sea level. The surface is very rough, and is fit only for grazing, having a relief of about 500 feet between the valley of Sheep Creek and the top of Sheep Mountain.

The lower part of the Lance formation constitutes the surface rocks of the township, except in a small area on the top of Sheep Mountain. The soft somber-colored shale of this formation has been eroded into intricate badlands. The Ludlow lignitic member of the Lance is represented beneath the White River formation in Sheep Mountain by about 35 feet of yellow sandy shale and soft sandstone, with a thick bed of lignite at the base. The White River formation, about 100 feet thick, occupies the small area at the top of Sheep Mountain and consists of soft white marl and thin beds of sandstone.

The only bed of lignite exposed in the township occurs at the base of the Ludlow lignitic member of the Lance. At location 688, in sec. 8, it is 1 foot 6 inches thick, but the area underlain by it is very small and almost inaccessible.

T. 16 N., R. 9 E.

The surface of T. 16 N., R. 9 E., is gently rolling and grass-covered, except in the western part, where the southeast end of the Slim Buttes rises in an almost impassable cliff 400 to 500 feet above the plain. The nearly flat top of the mesa is covered by a dense growth of grass, together with a few pine and cedar trees, but the plains east and north of the buttes are almost treeless. The land in the latter area has been settled by farmers who can, by the use of proper dry-farming methods, raise crops of wheat, oats, flax, etc. The JX ranch, in the valley of Antelope Creek, is one of the oldest stock ranches of the region.

The soft shale of the lower part of the Lance formation forms the surface rock in the largest part of the township. The Ludlow lignitic member of the Lance, represented by about 75 feet of yellow sandy shale and soft sandstone, is exposed around the edge of the Slim Buttes mesa and on the divide north of the JX ranch. Above this, in the Slim Buttes, is a mass of white clay, marl, sandstone, and conglomerate about 200 feet thick, which is assigned to the White River and Arikaree (?) formations. The rocks in the vicinity of the Slim Buttes, especially along their southern face, are much

disturbed, and the true structure is obscured by landslides. In the valley and plains part of the area the rock structure is obscured by a heavy mantle of soil.

Several isolated exposures of lignite were found near the base of the Ludlow lignite member of the Lance formation, but owing to the slumping it was impossible to make exact correlations, hence the exposures are shown on the map as unconnected outcrops. At a single place (location 692; see Pl. XI) the lignite has a thickness of 3 feet. No prospecting or mining has been done in this township. The following sections of thinner beds were measured, but are not shown on Plate XI:

Sections of lignite beds in T. 16 N., R. 9 E.

No. on Pl. I.	Location.	Section.	Ft.	in.	No. on Pl. I.	Location.	Section.	Ft.	in.
689	NE. ¼ sec. 30..	Lignite.............	2	0	693	SW. ¼ sec. 22..	Lignite.........	1	0
							Interval...........	10	0
690	NW. ¼ sec. 29..	.....do..............	1	11			Lignite.........	2	0
691	SE. ¼ sec. 29...	.....do..............	1	9			Total section.	13	0
							Total lignite..	3	0
					694	SW. ¼ sec. 16..	Lignite.............	1	4

T. 17 N., R. 9 E.

The gently undulating prairie which is characteristic of this part of the field is surmounted in the southwest corner of T. 17 N., R. 9 E., by Flat Top Butte, a small mesa which stands nearly 200 feet above the surrounding country. The soil in most of the township is a rich sandy loam, and crops of small grains have been raised on a number of small farms recently established in the township. An excellent spring in sec. 32 issues from rocks near the base of the White River formation.

The lower part of the Lance formation occupies a large area in the valleys of Rabbit Creek and its tributaries and along the south edge of the township. The Ludlow lignite member of the Lance is represented by a small thickness of sandy shale and thin-bedded sandstone, occupying the higher portions of the township, except in Flat Top Butte, where about 100 feet of the White River and Arikaree (?) formations is exposed. At the northwest angle of the butte the clay and sandstone of the White River formation show very marked cross-bedding, with angles of 20° to the horizontal. The bedrock in this part of the field is almost wholly obscured by the heavy mantle of soil, but from a study of a few exposures in this and adjacent townships the rock structure was determined. The rocks of the Lance formation dip to the northeast at about 40 feet to the mile.

The only lignite bed exposed in the township shows the following section:

Section of lignite bed at location 695, in sec. 25, T. 17 N., R. 9 E.

	Ft.	in.
Shale, brown.		
Lignite		2
Shale, brown	2	6
Lignite	1	6
Shale, brown.		
Total section	4	2
Total lignite	1	8

A well drilled in the NE. ¼ SE. ¼ sec. 25 is reported to have passed through the following formation:

Record of well in NE. ¼ SE. ¼ sec. 25, T. 17 N., R. 9 E.

	Ft.	in.
Soil	4	0
Clay, blue	10	0
Sandstone, hard	4	0
Lignite		8
Sandstone, hard	36	0
Clay, greenish, sticky, with occasional partings of sandstone	36	0
Lignite		6
Clay, greenish, sticky, with occasional partings of sandstone	30	0
Total section	121	2
Total lignite	1	2

Evidently this well passed through the Ludlow lignitic member of the Lance into the somber-colored shale of the lower part of the formation.

T. 18 N., R. 9 E.

The surface of T. 18 N., R. 9 E. is gently rolling and in large part cultivated, so that the underlying rocks are exposed in only a few places. The soil, which has resulted from the disintegration of soft sandstone and sandy shale, is a rich sandy loam and is well adapted to the raising of wheat, flax, rye, and oats, as well as potatoes and other garden products. At the time of examination in 1911 very few quarter sections of land in this township remained uncultivated. A few rather prominent but small rugged buttes rise above the general level of the plain and constitute well-known landmarks.

The somber-colored shale of the Lance formation outcrops in the valley of Gap Creek, in secs. 35 and 36, and the Ludlow lignitic member forms the surface rock in the remainder of the township except for a small area of the White River formation in the tops of low hills in sec. 5. The beds of the Lance formation dip to the northeast at about 25 feet to the mile.

A bed of lignite outcrops along the stream in sec. 4, and sections of it are given below, but it does not attain valuable thickness in the

township, and its correlation with the beds exposed in the township to the north is not known because the rocks between the exposures are covered by soil and grass.

Sections of lignite bed exposed in sec. 4, T. 18 N., R. 9 E.

No. on Pl. I.	Location.	Section.	Ft.	in.	No. on Pl. I.	Location.	Section.	Ft.	in.
699	NW. ¼ sec. 4..	Shale, brown.			701	NE. ¼ sec. 4...	Clay, yellow, sandy.		
		Lignite........	1	10			Lignite........	1	6
		Shale, brown.					Shale, brown......	7	0
700	NW. ¼ sec. 4..	Clay, yellow, sandy.					Lignite........	1	0
		Shale, brown......		5			Shale, brown.		
		Lignite........	1	6			Total section.	9	6
		Shale, brown.					Total lignite.	2	6
		Total section.	1	11					
		Total lignite.	1	6					

Near the tops of three rather prominent buttes in secs. 10, 11, and 33 a bed of lignite is exposed, which attains a total thickness of 4 feet of good lignite separated into two benches at one locality (No. 698, Pl. XI), but the bed underlies only a small area at the top of the butte and has only 20 or 30 feet of cover, hence is of little commercial value. Other sections exposed on this bed are as follows:

Sections of upper lignite bed exposed in T. 18 N., R. 9 E.

No. on Pl. I.	Location.	Section.	Ft.	in.	No. on Pl. I.	Location.	Section.	Ft.	in.
696	SE. ¼ sec. 32...	Sandstone.			697	SE. ¼ sec. 11...	Clay, yellow, sandy.		
		Shale, brown......	1	3			Lignite........	2	5
		Lignite........		4			Shale, brown.		
		Shale, brown..	1	6					
		Lignite........	1	9					
		Shale, brown.							
		Total section.	4	10					
		Total lignite.	2	1					

This bed is probably the same as that which underlies two small hills in secs. 34 and 35 of the township to the north.

T. 19 N., R. 9 E.

The South Fork of Grand River, which crosses three sections in the northern part of T. 19 N., R. 9 E., is one of the few perennial streams of the region and occupies a broad, open valley through which it flows in a widely meandering course. The run-off from the township is carried by this river. Between the level of the river in sec. 2 and the highest points to the south, in sec. 32, at 3,070 feet above the sea, there is a difference in altitude of about 400 feet. One very striking topographic feature in this part of the field is the flat-topped hills that are capped by thin beds of resistant sandstones. These are

especially prominent in secs. 9, 10, 15, and 16. The surface of the township is deeply dissected by numerous small streams, so that areas suitable for cultivation are scarce and most of the township is still used for grazing. The Ronan ranch, in sec. 11, is the only large ranch in the area, and only a few of the homesteaders who have recently taken up land have met with sufficient success to allow them to remain. Excellent springs issue from the sandstone ledges in the vicinity of Hogarth ranch, which is in sec. 4 of the township to the south. Only a few wagon roads and trails traverse the area, and these follow the easiest routes laid out by the old settlers. Most of the roads lead to Reva post office, in the township to the west.

Nearly all the rocks exposed in this township belong to the Lance formation. The lower rocks along the river consist of somber-colored cross-bedded sandy shale, with carbonaceous beds that locally merge into lignite. Above this part of the section the strata are yellow and more sandy and contain several beds of indurated ripple-marked cross-bedded sandstone, which give rise to very rough topographic features. This series, about 350 feet thick, is referred to the Ludlow lignitic member of the Lance and embraces all the valuable beds of lignite that are found in this part of the field.

Small erosion remnants of the White River formation are preserved in secs. 32 and 33. The rocks are almost white, some of them greenish white, and in the main are clay and fine-grained sandstone containing siliceous lentils. Along the main drainage channels there are some recent deposits of sand and alluvium.

Considered as a whole, the strata of this township are essentially horizontal, though there is an apparent northeasterly dip of about 15 to 30 feet to the mile. Here and there the beds are disturbed more than usual, some of them dipping as much as 5°. At first sight this condition seems to be due to local folding, but it may indicate the slope on which the sediments were deposited or it may possibly be due to the slipping of the unconsolidated material out from one side of a hill, allowing the cap of sandstone to settle unequally.

Four beds of lignite occur in this township. The lowest one is on the south bank of Grand River, and measurements of it were taken at locations 721 to 724, 726 and 727, and at location 725, in sec. 31 of the township to the north. Detailed sections (Pl. IX) show that the bed ranges from 2 to 4 feet in thickness. No trace of this bed was found along the valley in the eastern part of the township. At location 724, in the SW. ¼ sec. 4, where the bed measures 2 feet 2 inches, a small amount of lignite has been taken out by the residents near by. At location 726, in the NW. ¼ sec. 6, there is an abandoned strip pit.

About 200 feet above this bed a second bed outcrops underneath the tops of the highest hills and buttes through the middle and

western parts of the township. At location 728, in a small butte in sec. 13, 2 feet of lignite is exposed, and the bed is of about the same thickness in the buttes in the center of the township, but along the western tiers of sections it is much thicker. A section measured at location 717, in the SE. ¼ SW. ¼ sec. 18, shows that the bed is there 5 feet 7 inches thick. However, on the south side of this small hill, in sec. 19, the bed is less than 2 feet thick. It seems possible that one of the beds at the small prospect at location 705, in the NW. ¼ sec. 31, is on the same bed of lignite. At this locality the upper bench is 2 feet 6 inches thick; the lower bench was covered by the dump from the upper bench, but was reported to be 3 feet thick. At location 707, near the east line of sec. 24, T. 19 N., R. 8 E., near the "big stone cairn," 2 feet of lignite was measured, and at location 708, in sec. 25, there is 2 feet 10 inches of fair lignite in the same bed. The variation in thickness of this bed is shown graphically by secs. 705, 706, 717 to 720, and 728, Plate IX.

A third bed of lignite occurs nearly 100 feet above the bed just described, and small areas underlain by it remain in the southwest corner of the township. Measurements show that the bed ranges from 3 feet 4 inches to 6 feet in thickness. Detailed sections at locations 713 to 716, 702, 703, and 704 are given on Plate IX. In a small gully in secs. 19, 20, 29, and 30 and also in the east side of sec. 20 measurements of lignite were made, but the beds could not be correlated. Sections measured at locations 709, 710, and 712 are shown on Plate IX.

T. 20 N., R. 9 E.

T. 20 N., R. 9 E., is drained directly or indirectly by the South Fork of Grand River, which meanders in a general easterly direction through the south tier of sections. The river is one of the few perennial streams of this field, and at flood times is joined by several small streams from the northwest. It drains all but the northeast corner of the township, which is drained by Big Nasty Creek. Fairly good water is obtained in wells at depths of 50 to 200 feet.

There is a total relief of about 500 feet. The highest points are in the extreme northwest corner and have an elevation of about 3,000 feet above sea level. The east side of the township is rolling and uneven, but the northwestern and middle parts are decidedly rugged. Between the several small streams which meander through narrow valleys approximately parallel to the strike of the rocks there are high, narrow, rugged divides, along the sides of which the rocks are well exposed. The valley of Grand River is about 2 miles wide, but is too sandy for attractive farm land.

The roughness of the surface makes successful farming in this township an impossibility, except in a few small areas along the stream valleys. The Olsen ranch, in sec. 21, the Leadbeater, in sec.

36, and the Wagner, in sec. 7, are small stock ranches and constitute the principal permanent settlement. Homesteaders have taken up the more favorable tracts of land and are attempting to raise flax, wheat, and other small grains. Wagon roads for the most part follow the old trails, which were laid out in the early days along the easiest lines of travel.

Aside from the recent deposits along the south fork of Grand River and the main creeks, the rocks belong to the Lance formation. About 400 feet of strata are exposed, and so far as noted they are essentially horizontal, having a northeastward dip that does not exceed 15 or 20 feet to the mile.

The lower 50 or 100 feet of rocks exposed along South Fork of Grand River are somewhat more shaly than the upper beds. They are gray, drab, and in places brown in color, and here and there they contain a small lignite bed of no value. The upper beds, which are called the Ludlow lignitic member of the Lance, are more sandy and lighter in color, some of them being almost white and others buff or yellow. No fossils were collected from any of the rocks in this township, but their age is determined by correlation with rocks in adjacent townships.

Several beds of lignite outcrop in this township. Some are of considerable thickness, but others are thin and lenticular. The more valuable beds were mapped in the field in considerable detail, and their outcrops are shown on Plate I. In general, the beds are limited to the middle and northwest corner of the township. The lowest bed mapped is at the base of the Ludlow member and is the same as the lowest bed mapped in T. 20 N., R. 8 E.; in T. 19 N., R. 9 E.; and in sec. 32, T. 20 N., R. 10 E., and possibly the same as the bed mapped east of Glendo post office, at the junction of Big Nasty Creek and the South Fork of Grand River. Only two measurements of the bed were taken in this township—one at location 729, in the NE. ¼ sec. 32, (see Pl. IX), where only 10 inches of lignite is exposed, with an 8-inch bed 6 feet below, and the other at location 725, in sec. 31, where the bed is 3 feet 8 inches thick.

About 100 feet above this bed is a second lignite. Owing to the fact that in many places outcrops are separated by grassy slopes, there is some doubt as to the accuracy of correlation, but exposures at locations 739, 741, and 743 to 747 are thought to be on this bed. Details of these measurements are given on Plate IX. At location 745, in sec. 27, a small mine has been opened on this bed. The bed ranges in thickness from 11 inches at location 747 to 4 feet 5 inches at location 745, and only here and there is it of even local importance. At location 742 in section 14 a thin bed is exposed, but its correlation with other beds was not determined.

About 50 feet above this bed is a third, which was measured at locations 730, 740, 732 to 738, 769, 774, and 776. (See Pl. IX.) In

thickness it ranges from 6 inches at location 736, in sec. 21, to 5 feet 4 inches at location 737, in sec. 22. At location 776, in sec. 5, the bed is only 8 inches thick, and at many other places it holds about the same thickness. Its elevation is from 2,770 to 2,780 feet above sea level.

About 20 or 30 feet above it, in sec. 18 and vicinity, occurs a fourth bed which ranges in thickness from 6 inches along the road in the SE. ¼ NE. ¼ sec. 18 to 1 foot 6 inches at location 731.

About 40 or 50 feet above the thin bed last mentioned is the only valuable bed in the township, and its outcrop was traced in detail. The measurements at locations 750 to 758, 760 to 765, 767 and 768, and 770 to 773 (shown in detail on Pl. IX) are considered to be on this bed. Its altitude is from 2,800 to 2,840 feet, the northeastern exposures being the lower. It is possibly the same bed as the Widow Clark bed in T. 21 N., R. 7 E. At the Olson mine (location 753), in the SW. ¼ SE. ¼ sec. 17, the bed is 11 feet 4 inches thick, and at the Newcomb mine (location 762), in the SW. ¼ SW. ¼ sec. 10, it contains 10 feet 8 inches of first-class lignite. A sample was taken at the Newcomb mine for analysis (No. 15062), which was made by the Bureau of Mines. Although in the main this bed is persistent it varies decidedly from place to place. For instance, at location 764, in the NW. ¼ NE. ¼ sec. 8, only 1½ miles west of the Newcomb mine, the bed is but 2 feet 6 inches thick and is badly split by shale. In the township to the north the bed thins to about 3 feet. Its quality, as shown by the analysis, is good, and field inspection at other places revealed little impurity. A considerable part of the northwest corner and middle of the township is underlain by this lignite, with cover ranging from a few feet to about 150 feet.

The bed at location 759, in sec. 23, is shown graphically on Plate IX. It lies above the Widow Clark bed.

T. 21 N., R. 9 E.

The valley of Big Nasty Creek, which crosses T. 21 N., R. 9 E., from northwest to southeast, is fairly broad and open, as is that of a large stream leading southeastward from the Lodgepole Buttes and joining Big Nasty Creek in sec. 35. Both of these streams follow markedly meandering courses. The southwest corner of the township is very rough and of a somewhat badland character. The northwest corner is high and mesa-like and is a part of the upland which surrounds the Lodgepole Buttes. The remaining portions are rough, broken, and grass-covered. The total relief is in the neighborhood of 400 feet, the highest points being in sec. 11, at 3,000 feet above sea level, and in the northwest corner of sec. 6, at 2,980 feet.

Nearly every desirable quarter section has been filed upon by homesteaders. A small tract of land has been irrigated on the Shirley ranch, in sec. 9, and a fine crop of wheat was raised there in

1912. The Howard ranch, one of the oldest in this vicinity, is in sec. 19. Along Big Nasty Creek and its large tributary in the middle of the township there are small areas of irrigable land, but the supply of water is rather meager. Watson post office, in sec. 14, receives mail from Reeder, N. Dak.

The total thickness of rock exposed in this township is about 400 feet. The lower 50 or 75 feet of strata exposed along the banks of Big Nasty Creek consist of dark-colored shale, with beds of brownish sandstone and thin beds of lignite. They carry characteristic ferruginous nodules, which, after the rocks are disintegrated, remain on the weathered surface as brownish or reddish rounded masses. The soil resulting from the breaking down of this shale is gumbo-like and supports but little vegetation.

The succeeding rocks are more sandy and contain a number of lignite beds. These rocks, which cover the southwestern part of the township, are classed as the Ludlow lignitic member of the Lance formation. Rocks evidently belonging to the Lance formation exposed in the northeastern part of the township and occupying nearly the same stratigraphic position as those of the Ludlow member are placed in the Cannonball marine member of the Lance. The evidence for this correlation is a bed of oysters, *Ostrea glabra*, found in sec. 14. These fossils occur at about the same horizon as the marine fossils collected in T. 23 N., R. 9 E. The rocks consist of shale and sandstone. The division between the marine and lignitic members of the Lance along Big Nasty and Shirley creeks is arbitrarily drawn, because it was not mapped in the field.

The upper 75 feet of strata are classed as the Fort Union formation. They are light-colored and are mostly fine-grained sandstone, with interbedded soft shale and thin lenses of limestone. The sandstone is locally ripple-marked and somewhat cross-bedded. The limestone is light buff or brownish yellow on the oxidized surface and drab to bluish gray on the unaltered surface. In sec. 11 there are a great number of quartzite bowlders, which are derived from a thin stratum of siliceous rock occurring about 150 feet above the base of the formation. The nearest locality where such material is found in place is Anarchist Butte, in sec. 34, T. 22 N., R. 9 E., where the stratum has an altitude of 3,050 feet. The bowlders do not disintegrate readily, hence they remain scattered over the surface after the inclosing strata have been washed away.

Alluvium occurs along the two main creeks in an area about one-fourth to one-half mile in width.

The strata of this area are essentially horizontal. Altitudes on beds at three different horizons in northeastern Harding County show that the rocks in this general region have a dip to the northeast of about 20 feet to the mile.

Two valuable beds of lignite crop out in this township. The lower one is possibly the same as the Widow Clark bed of T. 21 N., Rs. 7 and 8 E. Its outcrop was traced with considerable difficulty, owing to the grass-covered slopes, but several measurements of the bed were obtained. On the north side of Big Nasty Creek at locations 784 to 786, in secs. 19 and 20, it is more than 3 feet thick. No evidence of its presence was detected in the area east of the northwest corner of sec. 9, although Mr. Korsca, at Watson, in sec. 14, reports having struck in his well about 3 feet of lignite, which may be the same bed. A small outlier of this bed occurs in secs. 27 and 21, and a measurement at location 783 (see Pl. IX) shows the bed to be 3 feet 10 inches thick. Five sections exposed at locations 642, 643, 777, 779, 780, and 781, in secs. 31 and 32, are supposed to be on this bed. Its thickness ranges from 2 feet 2 inches at location 779 to 4 feet 8 inches at location 642. At location 781 the bed is represented by carbonaceous shale. Further detailed information is given on Plate IX. In a narrow draw in the western part of sec. 31 (locations 642 and 643) there are two small strip pits on the bed, from which lignite has been mined by the near-by inhabitants.

About 50 feet above this bed is a second bed, which at locations 640 and 778 shows the detail given on Plate IX. At location 660A, in the SW. ¼ sec. 18, this bed is 2 feet 1 inch thick. In the SW. ¼ sec. 31 red rock possibly formed by the burning of the Giannonatti bed is exposed near the top of a hill, but no lignite is present. Along the bank of Big Nasty Creek at location 782, in sec. 28, occurs the lowest bed of lignite examined in this township. It is 2 feet thick and has been prospected for a fuel supply for local use.

T. 22 N., R. 9 E.

From the high grassy divide which crosses T. 22 N., R. 9 E., in a westerly direction, the surface slopes gradually to the North Fork of Grand River on the north and Big Nasty Creek on the south. The most imposing topographic feature of this part of the field consists of the Lodgepole Buttes, three rocky prominences, rising about 200 feet above the surrounding country, or 3,222 feet above sea level, in secs. 19 and 20 of this township and secs. 24 and 25 of the township to the west. The buttes are capped by a massive sandstone that protects the underlying strata from erosion. Another prominent topographic feature is Anarchist Butte, in secs. 33 and 34.

Although nearly every tillable section of land has been taken by homesteaders, there are now only a few settlers who are meeting with success in raising crops. A large number of tracts that were cultivated for a time are now overrun with weeds and Russian thistles, although unbroken meadow lands still produce an abundance of prairie grass. The average annual rainfall is not more than 15

inches, and there is little or no water for irrigation, so that the future success of farming depends on the development and use of adequate dry-farming methods. Good springs issue from the north and south sides of the Lodgepole Buttes. Aside from the springs the residents depend on wells, usually less than 200 feet deep, for water supply. Wagon roads can easily be built along section lines, and those few which still follow the old trails will ultimately be shifted to the section lines.

There are 420 feet of rocks exposed in this township, the lower 100 feet of which belong to the Ludlow lignitic member of the Lance formation and consist of interbedded shale, sandstone, and lignite. This member is exposed along the north side of the township, but erosion has not cut deeply enough in the south side to reveal its presence. Interbedded with the Ludlow member and below the Fort Union formation there is a thin series of strata assigned to the Cannonball marine member of the Lance. Although this member contains marine fossils in adjacent areas, none were found in this township, and as the rocks are similar lithologically to those of the lignitic member the boundary between these members is drawn arbitrarily.

The Fort Union formation overlies the Lance and is exposed in almost all parts of the township, but its maximum thickness (320 feet) is shown only in the Lodgepole Buttes. The lower part of the formation consists of interbedded buff to yellow shale and sandstone, with here and there a thin bed of limestone. The resistance to erosion of the thin indurated sandstones and limestones has produced the rather abrupt slopes leading from the creek bottoms to the upland. The quartzite of the Fort Union occurs in place about 95 feet below the top of Anarchist Butte, and the numerous quartzite bowlders which are scattered over the township, particularly along the south side, are derived from this stratum. In some places these bowlders are so thick as to interfere materially with the cultivation of the soil. The massive coarse-grained brownish sandstone that caps the Lodgepole and Anarchist buttes is from 50 to 75 feet thick and is stratigraphically the uppermost Fort Union rock in the State. The rocks of the Fort Union formation are in general lighter colored and more regularly bedded than those of the Lance.

A northeastward dip of the formations in this township amounting to about 20 feet in a mile is shown by the elevations determined on the upland area, which apparently is capped by the same series of sandstones and limestones.

The lowest bed of lignite that was found cropping out in this area has been mined at location 791 (see Pl. IX), in sec. 4.

At location 790, in sec. 4, the bed is 2 feet thick. This lignite bed is probably the same as the one mapped in sec. 36, T. 23 N.,

R. 9 E., and in the vicinity of Bloom. It is possibly the same as that mapped on the north side of the township to the south, but of this there is no direct evidence.

A second lignite bed underlies the Lodgepole Buttes, and at location 788, in sec. 19, where its thickness is 4 feet, a small mine has been opened on it. In a draw near the northwest quarter corner of sec. 30 a second mine has been opened on a bed of lignite possibly the same as the one on the north slope of the buttes. The mine when visited was so badly caved that no section was obtained. The altitude of the bed as determined on the north slope of the buttes is 3,020 feet. The bed is possibly the same as that mapped near Lodgepole post office.

T. 23 N., R. 9 E.

The drainage of T. 23 N., R. 9 E., goes into the North Fork of Grand River and its small tributaries. The river in very dry seasons is intermittent, although classed as a perennial stream. The total relief of the surface is 300 feet, and the highest determined point is along the south township line in sec. 32. The river at its lowest point in sec. 24 has an altitude of 2,600 feet. A considerable portion of the upland consists of broad, flat stretches of treeless, grass-covered country or cultivated fields. The uplands have a rather precipitous boundary, caused by the ledges of sandstone and limestone, which resist erosion. The open valley of the North Fork of Grand River is about a mile in width. The physiographic expression of this area is one of maturity, the drainage being well established, the streams meandering over their valley floors, the uplands being almost entirely dissected, and no undrained areas remaining.

Practically all the land has been taken up in homesteads and fairly good crops of wheat and flax are grown. If the precipitation were greater and more evenly distributed over the year, the soil would be productive and the country prosperous. Bloom post office is in sec. 24, along the State line.

The lower 75 to 100 feet of rocks exposed along the North Fork of Grand River are composed of shale, lignite, calcareous sandstone, and sandy limestone. The part including two lignite beds is nonmarine, but the part below the lowest exposed lignite is marine at least in places and that above the upper lignite for a few feet is also marine. Marine Cretaceous fossils collected in secs. 24 and 36 indicate transgression of the sea at the close of Lance time. The marine beds are included in the Cannonball marine member of the Lance, and the nonmarine beds in the Ludlow lignitic member.

A few feet of the Fort Union formation caps the interstream areas. The rocks are chiefly thin beds of decidedly ripple-marked, somewhat resistant sandstone, and thin lenses of limestone. The limestone is

light buff to yellow on the oxidized surface, but when broken o the fresh surface is drab or bluish. It has a conchoidal fracture a is very dense in texture.

As determined from the altitudes of the lignite beds and the le stretches of upland, which are apparently capped by the same led of sandstone and limestone, the rocks have a slight eastward dip about 20 feet to the mile.

Two beds of lignite crop out in the township. The lower one locally known as the Billy Green bed. At location 797 (see Pl. I near the old Green ranch, both beds were measured.

East of Bloom, at location 793, the lignite is only 1 foot thick, o one of the lower two benches in the previous section being foun The bed was traced to location 792, in the SE. ¼ sec. 21, where t section given in Plate IX was measured.

A few loads of lignite have been mined at this place, but the bed badly split by shale partings and on the whole seems to be of po quality. The general low grade of the lignite is shown by the fact th the people living in this immediate vicinity would rather, when the can afford it, drive to the railroad and buy Roundup or Hockin Valley coal. The correlation of the Billy Green bed with beds i adjacent townships was not attempted and probably can not b accurately made. However, a bed that crops out in T. 23 N., R. 1 E., is apparently the same.

About 40 to 50 feet above the Billy Green bed occurs the second bed of lignite, on which measurements were made at locations 789, 797, 794, 795, 796. (See Pl. IX.) The bed is thickest in sec. 36, where at a small mine (location 794), 3 feet 2 inches of very good lignite is exposed. At location 795, at a spring, the bed is 2 feet 10 inches thick. The bed was mapped about half a mile northward from location 795, but the best measurement obtainable was 1 foot of lignite at location 796. A thickness of 4 feet of lignite was reported to have been found in a well in the NW. ¼ sec. 6, T. 22 N., R. 10 E., at a depth between 40 and 60 feet. This is probably the same bed of lignite. This bed is exposed at location 793, in the middle of sec. 24, but is only a few inches thick. At all other places in this township where the bed was measured it is less than 2 feet thick and its outcrop was not mapped in detail. In the western part of the township no evidence of this lignite or even a lower bed was found.

T. 16 N., R. 10 E.

A gently rolling grass-covered prairie constitutes the surface of a large part of T. 16 N., R. 10 E. The small town of Vernal, in sec. 7, is surrounded by a large number of successful farms.

The surface rocks belong to the Lance formation, the Ludlow lignitic member occupying a small area along the divide north of

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Antelope Creek. From such data as the few exposures of rock afford, it is evident that the beds dip slightly northeastward. So far as is known to the writers, no bed of lignite is exposed in the township, and the underlying rocks are believed not to contain lignite in this part of the field.

T. 17 N., R. 10 E.

Rabbit Creek, which crosses T. 17 N., R. 10 E., from west to east, occupies a rather broad valley, on the south side of which the land rises rapidly to a high divide in the southern part of the township. Sorum, in sec. 7, is a small but prosperous town on the surveyed line of a branch of the Chicago, Milwaukee & St. Paul Railway and forms the trading center for a large farming community.

The surface rocks belong to the Lance formation. The Ludlow lignitic member of the Lance is exposed in the high divide in the southern part of the township, where it has a maximum thickness of about 200 feet. The lower sandstones of the member also cap the divides north of the creek. The formation dips gently northeast.

Although the gently rolling surface of this township is in most places grass-covered, lignite beds are exposed at a number of places. The thickest bed crops out near the top of a small hill at location 799, in sec. 28 (see Pl. XI), where a small mine has been opened and a few loads of lignite have been removed. Although the bed has a thickness of 3½ feet at this locality, there is hardly sufficient cover anywhere to prevent the weathering of the lignite, and consequently it is not workable except for local use. The Knudsen mine, at location 811, in sec. 2 (Pl. V, *A*, p. 44), is the only place in the township where lignite has been mined in a commercial way. The mine was opened by Andrew H. Knudsen in 1910 and was worked by stripping the overburden, but at the time of examination, in August, 1911, several hundred feet of narrow entries had been driven close together, leaving no space for rooms. It is reported that during the winter of 1910–11 more than 100 wagon loads of lignite, or approximately 200 tons, was sold to the farmers of the surrounding country. The following section of the bed was measured near the end of the workings, about 150 feet from the opening, where a sample of the lignite was taken for analysis (No. 12454, p. 42):

Section in Knudsen mine, at location 811, sec. 2, T. 17 N., R. 10 E.

	Ft.	in.
Shale, sandy.		
Lignite, fair (included in sample)		10
Lignite (included in sample)	1	9
Shale, brown		4
Clay, lignite, bony		7
Total section	3	6
Total lignite	3	2

At location 810, in sec. 2, the same bed of lignite as the one mined at the Knudsen mine is only 2 feet 6 inches thick.

Thinner lignite beds are exposed at a number of localities in the township, but no attempt was made to correlate them. The locations where measurements were made are shown on Plate II (in pocket), and the following sections indicate the character of the beds:

Sections of lignite beds in T. 17 N., R. 10 E.

[In addition to those shown on Pl. XI.]

No. on Pl. II.	Location.	Section.	Ft.	in.
798	SE. ¼ sec. 29	Shale, sandy.		
		Shale, brown	2	0
		Lignite		6
		Shale, brown	1	3
		Lignite, poor	1	8
		Shale, brown.		
		Total section	5	5
		Total lignite	2	2
800	SE. ¼ sec. 30	Clay, sandy.		
		Lignite		6
		Shale	2	6
		Lignite, poor	2	6
		Shale, brown.		
		Total section	5	6
		Total lignite	3	0
801	NW. ¼ sec. 28	Soil.		
		Lignite	1	6+
		Base not exposed.		
802	SW. ¼ sec. 19	Clay, sandy.		
		Shale, brown	1	6
		Lignite	1	6
		Shale, brown.		
		Total section	3	0
		Total lignite	1	6
803	NW. ¼ sec. 19	Sandstone, gray.		
		Lignite	1	1
		Shale.		
804	SE. ¼ sec. 18	Sandstone, light gray	4	0
		Shale, brown		3
		Lignite		11
		Shale, brown		6
		Lignite		6
		Shale, brown		2
		Lignite	1	6
		Shale, brown.		
		Total section	7	10
		Total lignite	2	11
805	NE. ¼ sec. 18	Shale.		
		Lignite		3
		Shale		8
		Lignite		6
		Shale		1
		Lignite		11
		Interval, about	25	
		Shale, gray		8
		Lignite	1	6
		Shale, brown.		
		Total section	29	7
		Total lignite	3	2
806	NE. ¼ sec. 18	Shale, brown, sandy.		
		Lignite		9
		Shale		8
		Lignite		2
		Shale		2
		Lignite	1	1
		Shale, brown	1	9
		Lignite		7
		Shale, brown.		
		Total section	5	2
		Total lignite	2	7
807	NW. ¼ sec. 18	Sandstone.		
		Shale, brown		3
		Lignite	2	0
		Shale, brown.		
		Total section	2	3
		Total lignite	2	0
808	NW. ¼ sec. 18	Soil.		
		Lignite	1	9
		Shale, brown.		
809	NW. ¼ sec. 3	Lignite, about	2	
812	SW. ¼ sec. 1	Shale.		
		Lignite		6
		Shale, brown	3	0
		Lignite	1	7
		Shale, brown.		
		Total section	5	1
		Total lignite	2	1

T. 18 N., R. 10 E.

The surface of T. 18 N., R. 10 E., is a rolling grass-covered prairie, parts of which have been broken for cultivation in the last few years. By far the larger part of the township is comparatively level and forms good farm land, the maximum difference in altitude between the valley in sec. 33 and the top of White Hill, in sec. 4, being only about 200 feet. A large number of farmers have settled in this part of the field.

A small area of the lower part of the Lance formation is exposed in secs. 31, 32, and 33, and the Ludlow lignitic member of the Lance, exposed south of the South Fork of Grand River, reaches its maximum thickness (about 325 feet) in the divide along the northern edge of the township. White Hill, in sec. 4, is capped by about 50 feet of the White River formation and rises as a prominent landmark above the general level of the meadow land.

A single bed of lignite was measured at location 813, in sec. 20, where it is 2 feet 8 inches thick and lies between beds of brown shale.

Part of the land in the southeast corner of the township is probably underlain by the lignite bed worked at the Knudsen mine, in sec. 2, T. 17 N., R. 10 E., but as this bed is less than 3 feet thick at all points along its outcrop, it is thought to be of little commercial importance. The bed of lignite mined at the Jones mine, at location 824, in sec. 35, T. 19 N., R. 10 E., where it is about 5 feet thick (see Pl. XI), in all probability underlies a part of the northeast quarter of this township. A lignite bed 1 foot 6 inches thick, reported at a depth of 30 feet in a well at location 814, in sec. 13, may be at the same bed as that at the Jones mine.

T. 19 N., R. 10 E.

T. 19 N., R. 10 E., lies in the area known locally as The Breaks and, as that name indicates, the surface is deeply dissected, many of the small streams tributary to the South Fork of Grand River occupying narrow, steep-sided valleys more than 100 feet deep. Owing to this fact very little has been accomplished in attempts at farming in the township. There is a difference in altitude of about 300 feet between the valley of the South Fork of Grand River on the north and the Meadow flat in the southern part of the township.

The surface rocks belong to the Ludlow lignitic member of the Lance formation, nearly the entire thickness of which is represented. From data collected along the outcrops of lignite beds the rocks appear to dip gently to the northeast.

Several more or less valuable beds of lignite outcrop in the rough area north of the Meadow. The best and stratigraphically the highest bed was traced from a point near the west edge of the township eastward into T. 19 N., R. 11 E., and has a thickness varying from 1 foot 8 inches at location 815, in sec. 32, to 6 feet 1 inch at a small mine at location 821, in sec. 27. Farther east the bed is thinner, so that at location 895, in sec. 20, T. 19 N., R. 11 E., it is represented by only 2 feet of lignite. Two mines are located on this bed in the township; a small opening at location 821, where after stripping off the overlying rock the operators removed several loads of lignite; and the Jones mine (Pl. V, *B*, p. 44), at location 824, in sec. 35, which is worked from a number of drift openings. The bed

at the Jones mine is 5 feet 4 inches thick (see Pl. XI) and is overlain by 75 to 100 feet of cover. In mining, the upper bench of lignite, 1 foot 2 inches thick, is left as roof. In August, 1911, the mine workings consisted of a main entry about 200 feet long and numerous rooms on each side. Before the present system of mining was adopted seven parallel drifts were run into the side of the hill for distances of nearly 100 feet, but all except the one now used for a main entry were abandoned in 1909. The equipments of the mine included two cars, platform scales, and a small blacksmith shop. One man was working in August, 1911, and several wagon loads of lignite were sold daily. The output for 1910, which was sold to the farmers near by at $2.50 a ton at the mine, was 925 tons. The lignite as it comes from the mine is hard, brown, and woody, but it weathers too rapidly to stock successfully. Analysis 12453 (p. 42) was made on a fresh sample and represents the general character of the lignite in this mine. All the measurements taken on this bed (sections 815 to 828, 830, and 852) are shown graphically on Plate XI.

About 45 feet below the Jones bed lies a thin bed of lignite, which, probably because of its proximity to the more valuable bed above, has never been prospected. It varies in thickness, reaching a maximum of 2 feet 9½ inches. The variation is shown by the following sections:

Sections of lignite bed, 45 feet below the Jones bed in T. 19 N., R. 10 E.

No. on Pl. II.	Location.	Section.	Ft.	in.
834	SE. ¼ sec. 29	Shale, brown.		
		Lignite	1	3
		Shale, brown.		
835	NW. ¼ sec. 28	Shale, brown.		
		Lignite	1	5
		Shale, brown.		
836	SW. ¼ sec. 21	Sandstone, yellow.		
		Lignite	1	11
		Shale, brown.		
837	SW. ¼ sec. 22	Shale, brown.		
		Lignite	1	6
		Shale, brown		1½
		Lignite	1	2
		Shale, brown.		
		Total section	2	9½
		Total lignite	2	8
838	SW. ¼ sec. 22	Shale, brown.		
		Lignite	1	1
		Shale brown		3
		Lignite	1	0
		Shale, brown.		
		Total section	2	4
		Total lignite	2	1
839	SE. ¼ sec. 22	Shale.		
		Lignite	2	4
		Interval	22	0
		Lignite	2	0
		Shale, brown.		
		Total section	26	4
		Total lignite	4	4
840	NE. ¼ sec. 22	Shale, blue.		
		Lignite		10
		Shale, brown		3½
		Lignite	1	8
		Shale, brown.		
		Total section	2	9½
		Total lignite	2	6

A small strip mine has been opened at location No. 844, in sec. 23, on a bed of lignite 1 foot 9 inches thick, which occurs at a still lower horizon. Only a small amount of fuel had been mined previous to August, 1911.

Beds of lignite, either thin or of local extent, so that they were not correlated, except in a few places, are exposed at various localities in the township. Sections measured on these beds are as follows:

Sections of thin lignite beds in T. 19 N., R. 10 E.

[Not shown on Pl. XI or given above in text.]

No. on Pl. II.	Location.	Section.	Ft.	in.
831	SE. ¼ sec. 29	Soil.		
		Lignite	1	9
		Shale, brown.		
832	SE. ¼ sec. 29	Shale, brown.		
		Lignite	1	0
		Shale, brown.		
833	SW. ¼ sec. 28	Shale, gray.		
		Lignite	1	4
		Shale, brown.		
840	NE. ¼ sec. 22	Shale, bluish yellow.		
		Lignite		10
		Shale, brown		3½
		Lignite	1	8
		Shale, brown.		
		Total section	2	9½
		Total lignite	2	6
841	NW. ¼ sec. 16	Shale, light brown.		
		Lignite	1	9
		Shale, carbonaceous		5
		Shale, light brown.		
		Total section	2	2
		Total lignite	1	9
842	SE. ¼ sec. 4	Soil	2	
		Shale		8
		Lignite	1	9
		Interval	13	
		Lignite		8
		Shale, brown.		
		Total section	18	1
		Total lignite	2	5
843	NW. ¼ sec. 23	Shale, brown.		
		Lignite	1	9
		Shale, brown.		
845	NW. ¼ sec. 24	Soil	3	0
		Shale, brown		9
		Lignite	1	4
		Shale, brown.		
		Total section	5	1
		Total lignite	1	4
846	NE. ¼ sec. 14	Shale, light brown.		
		Lignite	1	10
		Shale, dark brown.		
847	SE. ¼ sec. 14	Shale, brown, sandy.		
		Lignite	1	10
		Shale, brown, lignitic.		
848	NE. ¼ sec. 12	Shale, brown.		
		Lignite	2	9
		Shale, yellowish brown.		
849	SE. ¼ sec. 1	Soil	3	0
		Lignite	1	4
		Shale, brown.		
		Total section	4	4
		Total lignite	1	4
850	SW. ¼ sec. 1	Clay.		
		Lignite	2	6
851	SW. ¼ sec. 1	Sandstone	3	0
		Shale, brown		8
		Lignite		3
		Shale, brown		9
		Lignite		1
		Sandstone		3
		Shale, brown		5
		Sandstone		5
		Shale, brown		2
		Lignite	1	9
		Shale, brown.		
		Total section	7	9
		Total lignite	2	1
853	NE. ¼ sec. 14	Sandstone.		
		Shale, brown		8
		Lignite	2	0
		Shale, brown.		
		Total section	2	8
		Total lignite	2	0

Part of the northeast quarter of this township is probably underlain by a bed of lignite that crops out along the South Fork of Grand River in secs. 26 and 35, T. 20 N., R. 10 E., and is described below.

T. 20 N., R. 10 E.

The South Fork of Grand River crosses the southern part of T. 20 N., R. 10 E., in a rather broad valley along which are several small areas of sand dunes. Big Nasty Creek, one of the perennial streams of the region, enters the township from the northwest and flows in a meandering course, joining the South Fork in sec. 24. In the river valley and in the valley of Big Nasty Creek there are

numerous tracts of cultivated land, but the upland area is rough and grass covered. Rock exposures are few.

The Ludlow lignitic member of the Lance formation, dipping gently eastward, constitutes the surface rock of nearly the entire township. In parts of secs. 1 and 2 the surface is formed by rocks of the Cannonball marine member, and along the South Fork of Grand River there is a narrow area, in which the lower part of the Lance formation is exposed. In most places, however, the lower Lance beds are covered by alluvium.

The lignite bed occurring at the base of the Ludlow member is the only one which has attracted attention in this township. In secs. 26 and 35 considerable prospecting has been done and some lignite has been removed by the farmers living in the vicinity. The bed, which is exposed in the south bank of the river, is comparatively uniform in thickness and contains about 3 feet 10 inches of good lignite, as shown by sections 858, 859, and 860, Plate XI. At locations 861 (see Pl. X), in sec. 23, near the mouth of Big Nasty Creek, a bed having a thickness of 1 foot 10 inches is supposed to be the same. At location 855, in sec. 32, there is a bed 1 foot 8 inches thick at the base of the Ludlow lignitic member of the Lance, which may be the same as the bed described above or it may be a separate lens. To the east, beyond the limits of the township, the bed is not exposed, but in sec. 28, T. 20 N., R. 11 E., there is apparently another lens of lignite at about the same horizon.

Several thin beds in the Ludlow member are exposed at different localities in the township and are represented by the following sections. The exact correlation of the beds is impossible because of the grass-covered surface between the exposures:

Sections of thin lignite beds in T. 20 N., R. 10 E.

[Not shown on Pls. X and XI.]

No. on Pl. II.	Location.	Section.	Ft.	in.	No. on Pl. II.	Location.	Section.	Ft.	in.
854	SW. ¼ sec. 36..	Shale, brown.			862	SW. ¼ sec. 2...	Lignite.........	2	2
		Lignite.........	2	1	863	NW. ¼ sec. 2..	Shale, gray.		
		Shale, black.					Lignite.........	2	2
856	NW. ¼ sec. 29.	Shale, brown.					Shale, brown.		
		Lignite.........	2	1	864	NW. ¼ sec. 2..	Shale, sandy.		
		Shale, brown.					Lignite.........	2	1
857	SE. ¼ sec. 19...	Clay.					Shale.		
		Lignite, poor...	1	4					
		Shale, brown.							

T. 21 N., R. 10 E.

The divide between the North and South forks of Grand River, consisting of a nearly flat plateau, crosses the northeastern part of

T. 21 N., R. 10 E., and is separated by a series of steep scarps from the lower country in the southern part.

The rocks that outcrop in the township belong to the Fort Union formation and to the Ludlow lignitic and Cannonball marine members of the Lance formation. About 150 feet of the lower part of the Fort Union crops out in the northeastern part of the township. With the exception of the upper 30 or 40 feet on Flat Top Butte, in sec. 10, these rocks are concealed by the mantle of soil. The topography and the character of the soil, however, indicate that sandstone is the principal rock. The Lance formation is represented along the south side of the plateau by about 250 feet of sandstone and shale, but the rocks are so deeply covered by soil that no definite conception of them could be obtained. It is probable that the upper 25 to 50 feet of this formation belongs to the Cannonball marine member and the remainder to the Ludlow lignitic member.

Lignite beds belonging to the Ludlow member and reaching a maximum thickness of 2 feet 10 inches are exposed in secs. 30, 33, and 34. Lignite near the top of the Ludlow member was also said to have been found in two wells in sec. 17. The sections of the beds at these places are as follows:

Sections of lignite beds in the Ludlow lignitic member of the Lance formation in T. 21 N., R. 10 E.

Location 865. SW. ¼ sec. 34.

	Ft.	in.
Shale, gray.		
Lignite, low grade	2	4
Shale, brown.		

Location 866. NW. ¼ sec. 33.

	Ft.	in.
Shale, light brown, fissile.		
Lignite, weathered	2	6
Lignite, low grade		4
Shale, light brown.		
Total lignite	2	10

Location 867. SE. ¼ sec. 30.

	Ft.	in.
Shale, gray.		
Shale, carbonaceous, with thin lenses of lignite	2	10
Shale, light brown		½
Lignite		6
Shale, light brown.		
Total section	3	4½
Total lignite		6

Location 868. SE. ¼ sec. 30.

	Ft.	in.
Shale, gray.		
Shale, carbonaceous, grading into bone and thin streaks of lignite	1	3
Lignite		7
Shale, light brown		½
Lignite		6½
Shale.		
Total section	2	5
Total lignite	1	1½

Location 869. SE. ¼ sec. 17.

Well reported to have passed through about 5 feet of weathered lignite at a depth of 30 feet.

Location 870. SE. ¼ sec. 17.

Well reported to have passed through 2 feet of weathered lignite at a depth of 30 feet.

The outcrops could be traced for only short distances, and the beds recorded above could not be definitely correlated.

A bed of lignite in the Fort Union crops out near the top of Flat Top Butte, in sec. 10, and is correlated with the valuable bed near Lodgepole, in T. 21 N., R. 12 E. At the only place suitable for

examination (location 871) the bed is 2 feet 2 inches thick but considerably burned. About 20 feet below the lignite there is a persistent layer of very hard quartzitic rock, remnants of which lie scattered over the tops of numerous hills in this and adjoining townships.

T. 22 N., R. 10 E.

The surface of T. 22 N., R. 10 E., is a broad, nearly flat plateau which has been to some extent dissected by Horse Creek and its tributaries. The land in the valleys is underlain by the Ludlow lignitic member and Cannonball marine members of the Lance formation, and the plateau surface by the lower part of the Fort Union formation. The mantle of soil is heavy, and at only a few places is it possible to find natural rock exposures.

A thin bed of lignite in the Ludlow lignitic member crops out in the valley of Horse Creek but is concealed except at three places, in secs. 1, 2, and 23 (locations 874 873, and 872, respectively), at each of which some prospecting has been done and lignite has been removed for local use. The average thickness of the bed is less than 2½ feet. The sections measured at these places are as follows:

Sections of a lignite bed in the Ludlow lignitic member of the Lance formation in prospect pits in T. 22 N., R. 10 E.

Location 872. NE. ¼ sec. 23.

	Ft.	in.
Shale, bluish gray, sandy.		
Lignite, woody texture	2	8
Clay.		

Location 873. NE. ¼ sec. 2.

	Ft.	in.
Shale.		
Lignite	1	10
Bottom of bed covered with water.		

Location 874. SE. ¼ sec. 1.

	Ft.	in.
Shale, brown.		
Lignite	2	0
Bed covered with water.		

A lignite bed outcrops in the valley of a small stream in sec. 5, where it is less than 2 feet thick and was not mapped. The bed was reported to be 2 feet 9 inches thick in a well at location 875, in the NW. ¼ sec. 8, and it was said that in a deeper well in sec. 10 two lignite beds were penetrated, the upper one 2 feet 6 inches thick and the lower one 6 feet 6 inches thick.

No lignite could be found in the Fort Union formation in this township.

T. 23 N., R. 10 E.

The greater part of T. 23 N., R. 10 E., is occupied by the broad valley of the North Fork of Grand River, which flows from west to east. Between the valley and the extensive uplands to the north and south is a series of steep scarps separated by nearly level benches. The upland is underlain by the lower sandstone of the Fort Union formation, and the rocks that crop out in the valley belong to the

Ludlow lignitic and Cannonball marine members of the Lance formation, which are fairly well exposed at a few points along the river bluffs.

A thin bed of lignite in the Ludlow member crops out on the south side of the river and is well exposed in the river bluffs in the western half of the township. West of sec. 28 it is less than 2 feet thick and was not mapped. In sec. 28, however, it reaches a thickness of 3 feet 3 inches with a 3-inch parting 1 foot from the top (section 878, Pl. X). East of that place the bed was found only at location 877, on the east line of sec. 36, where it is 1 foot 5 inches thick.

T. 16 N., R. 11 E.

Several small areas of badlands are found along the stream courses in T. 16 N., R. 11 E., although a large part of the land is rolling and partly grass-covered. The soil, which is the result of the disintegration of the argillaceous shale of the Lance formation, is not especially fertile, hence farming has been attempted at only a few localities. The low divide between Antelope Creek on the south and Rabbit Creek on the north extends across the center of the township.

No lignite beds of value are exposed in this township, and although the bedrock is largely obscured by soil, there is little possibility that good lignite beds will be found beneath the surface, because the Lance formation contains only thin beds of lignite in this part of the field.

T. 17 N., R. 11 E.

North of Rabbit Creek, in the western part of T. 17 N., R. 11 E., the surface rises rapidly, culminating in secs. 7 and 8 in a narrow ridge, the top of which is about 250 feet above the level of the creek. To the south, however, except where cut by small streams, the surface is a rolling prairie. Rabbit Creek occupies a rather narrow, meandering channel cut several feet below the average valley level. Except along the north bank of Rabbit Creek there are very few rock exposures, the character and attitude of the underlying formations being obscured by a heavy mantle of soil. Numerous small farms are located in the broad, open valley that extends northward from Rabbit Creek through the center of the township.

The lower part of the Lance formation is exposed in the southern two-thirds of the township, along the valley of Rabbit Creek, and contains thin beds of lignite near the top. The Ludlow lignitic member outcrops in the ridges north of Rabbit Creek, where it contains one economically important bed of lignite about 100 feet above the base. There are numerous more or less resistant sandstone beds in it which give rise to the rugged ridges north of the main stream. All the strata dip very gently north.

One of the lignite beds near the top of the lower part of the Lance has been worked for several years at location 879, in sec. 7, at the Phillips mine, which in 1911 consisted of four drift entries from each of which rooms had been turned. From one of these entries, 200 feet long, lignite had been removed recently, but the others had been idle for more than a year. The bed in the mine ranges in thickness from 1 foot 9 inches to 2 feet 5 inches and has an excellent shale roof and floor. Practically no props have been necessary to keep the mine in good condition, except where part of the roof has been removed along the entries. The fresh lignite is hard and black, has cleavage planes fairly well developed, and shows little of the woody structure so prominent in most of the lignite of this region, thus suggesting that it should perhaps be classed as subbituminous, like the coal of near-by fields in eastern Wyoming and Montana. It is rather significant, however, that although differing markedly in physical properties, the lignite from this mine has almost the same chemical composition as that mined at the Jones mine, in T. 19 N., R. 10 E., and described on page 128. A sample of the lignite was taken from a room near the end of the longest entry in the Phillips mine, and the analysis of it (No. 12488) is given in the table on page 42.

In several small areas east of the Phillips mine the lignite has been burned, and the resulting red soil and rock indicate the former position of the bed. A bed supposed to be the same is exposed at location 881, on the east side of a small valley in sec. 17, and contains 3 feet 9 inches of lignite. Beyond this place to the east the bed could not be found. Other beds of lignite of lesser value occur near the top of the lower part of the Lance. The sections obtained at locations 879, 880, and 881 are shown in Plate XI. Others in secs. 16 and 17 are as follows:

Sections of lignite beds in the lower part of the Lance formation, in T. 17 N., R. 11 E.

[In addition to those shown on Pl. XI.]

No. on Pl. II.	Location.	Section.			No. on Pl. II.	Location.	Section.		
			Ft.	in.				Ft.	in.
882	SW. ¼ sec. 17..	Shale, brown.			883	NE. ¼ sec. 16..	Shale, brown, sandy.		
		Lignite..........	1	0			Lignite..........	1	4
		Shale brown.					Shale, brown.		

The thickest bed of lignite exposed in this township occurs in the Ludlow lignitic member of the Lance and outcrops well up in the ridge north of Rabbit Creek. No mines have been opened on the bed, although it contains 3 feet 8 inches of clean lignite at location 884 and 3 feet 10 inches at location 885.

T. 18 N., R. 11 E.

T. 18 N., R. 11 E., lies within the typical meadow area of Perkins County and the surface is generally flat and is grass-covered except where it is cultivated. The soil is the result of the disintegration of the sandy shale and soft sandstone of the Ludlow lignitic member of the Lance, and is fertile and well adapted to the raising of small grains, potatoes, etc. Only a very few tracts still remain unappropriated by the farmer. Strool, one of the thriving business towns of Perkins County, is in sec. 19. In secs. 26 and 27 there is a prominent ridge covered with brown quartzite bowlders, some of them several feet in diameter, which may belong to the White River formation.

Lignite has been mined for local use at the Shear ranch (location 887), in sec. 26, where there is reported to be about 3 feet of lignite. In August, 1911, the pit was filled with water, so that only 2 feet of lignite was exposed. Thin beds of lignite are reported to have been found in a few wells in this vicinity, but none of economic importance are known.

T. 19 N., R. 11 E.

The surface of T. 19 N., R. 11 E., shows a difference in altitude of at least 300 feet between the level of the valley on the north and the high bench land in the southern portion. Numerous small streams flowing northward into the South Fork of Grand River dissect the surface so that most of it is too rough to be used for farming. The surface rocks, which are fairly well exposed, belong to the Ludlow lignitic member of the Lance and dip slightly northeastward.

Two beds of lignite, on each of which one small mine has been opened, attain a thickness of more than 2 feet 10 inches. The upper bed, represented by sections 888 to 892, reaches a thickness of nearly 8 feet at the mine at location 890, in sec. 19. Considerable lignite has been removed from this mine by stripping the overburden, but in future development it will be necessary to drift because of the thick mantle of rock and soil which overlies the bed. As will be seen by referring to the sections on Plate XI, this bed varies considerably in thickness, but at a number of places it is thick enough to be profitably mined.

Approximately 65 feet lower in the section the bed that is mined at the Jones mine, in the township to the west, is represented by sections 894 to 898, Plate XI. At the time of examination in 1911 the mine at location 894, in sec. 20, consisted of one drift entry more than 50 feet long which was badly caved and inaccessible. The bed is 4 feet 7 inches thick at the mouth of the entry. The amount of lignite removed is not known, but evidently it is considerable. Although exposed at several other localities in the township the bed is not thick enough to be of value except at the abandoned mine.

In addition to the two beds mentioned, several thin beds are exposed at several localities and a number of sections were measured. All the lignite sections obtained in the township are shown graphically on Plate XI or are presented in the following table:

Sections of lignite beds in T. 19 N., R. 11 E.

[In addition to those shown on Pl. XI.]

No. on Pl. II.	Location.	Section.	Ft.	in.
892	SW. ¼ sec. 27..	Soil.		
		Lignite.........	1	4
		Shale, brown.		
893	NE. ¼ sec. 27..	Shale, brown.		
		Lignite.........	2	9
		Shale, brown.		
898	NW. ¼ sec. 21..	Top not exposed.		
		Lignite.........	1	8
		Shale, brown.		
899	NW. ¼ sec. 17.	Shale, brown.		
		Lignite.........		11
		Shale, brown...		2
		Lignite.........	1	1
		Shale...............	3	
		Lignite.........	1	3
		Total section.	6	5
		Total lignite..	3	3
900	SW. ¼ sec. 17..	Soil................	8	
		Shale, brown.......		8
		Lignite.........	2	4
		Interval............	10	6
		Lignite.........	1	4
		Shale, brown.		
		Total section.	22	10
		Total lignite..	3	8
901	SW. ¼ sec. 8...	Shale, brown.		
		Lignite.........		9
		Shale, brown...		4
		Lignite.........		6
		Shale, brown.......	2	0
		Lignite.........	1	7
		Shale, brown.		
		Total section.	4	2
		Total lignite..	2	10
902	SE. ¼ sec. 7....	Shale, brown.		
		Lignite........		7
		Shale, brown..		2½
		Lignite........		10
		Shale, brown..		3½
		Lignite........		10
		Shale, brown..	1	6
		Lignite........	2	6
		Shale, brown.		
		Total section	6	9
		Total lignite.	4	9
903	NE. ¼ sec. 8...	Shale, brown.		
		Lignite........	2	6
		Shale, brown.		
904	SE. ¼ sec. 5....	Soil.		
		Shale, brown......		8
		Lignite........	1	6
		Shale, brown.		
		Total section	2	2
		Total lignite.	1	6
905	NE. ¼ sec. 5....	Shale, brown.		
		Lignite........	2	8
		Shale, brown.		
906	SE. ¼ sec. 1....	Soil.		
		Lignite........	2	3
		Shale, brown.		

T. 20 N., R. 11 E.

The southern part of T. 20 N., R. 11 E., is occupied by the broad valley of the South Fork of Grand River. South of the river the slopes are somewhat abrupt and the land is deeply dissected by small valleys, so that the rocks are fairly well exposed. North of the river the slopes are not nearly so steep, and good exposures can be found at only a few points.

The Cannonball marine member of the Lance formation crops out in the northern part of the township, and the Ludlow lignitic member of the Lance, about 300 feet in thickness, crops out in the valley slopes both north and south of the river. About 20 or 30 feet of the lower part of the Lance appears above the river level. The Ludlow

lignitic member, which is the surface rock over most of the township, consists of alternating beds of yellow sandstone, brown shale, and lignite. The sandstone in most places is unconsolidated and makes up nearly half of the total thickness.

Lignite beds are numerous, particularly in the lower part of the Ludlow member, but are everywhere thin and lenticular. In the river bluff at location 907, in the NE. ¼ sec. 28, five lignite beds are exposed in the lower 50 feet of the member. Some lignite has been removed for local use from the thickest of these beds. On the other side of the river, at location 908, in the NW. ¼ sec. 22, a still higher bed has been prospected and a considerable amount of lignite removed. The same bed was examined at location 909, in the NE. ¼ sec. 22, and at location 910, in the SE. ¼ sec. 13, and another still higher bed at location 911, in the NE. ¼ sec. 13. The sections measured at these places are given below. The same beds were examined at other points in the township but were not mapped.

Sections of lignite beds in Ludlow lignitic member of Lance formation in T. 20 N., R. 11 E.

Location 907. NE. ¼ sec. 28.

	Ft.	in.
Shale, light brown.		
Lignite		10
Shale, light brown	1	2
Lignite		7½
Shale, sandy	1	0
Lignite		7
Shale, brown and gray	3	3
Lignite		8½
Shale, brown	1	1
Lignite	1	7
Shale, brown		10
Shale, mudstone, blue	3	4
Lignite	2	3½
Shale and sandstone	29	0
Lignite		4½
Shale	3	0
Lignite		5
Shale.		
	50	1

Location 908. NW. ¼ sec. 22.

	Ft.	in.
Shale, brown.		
Lignite	2	7
Shale, brown.		

Location 909. NE. ¼ sec. 22.

	Ft.	in.
Shale, brown, sandy.		
Lignite	1	6
Shale		½
Lignite	1	0
Shale.		
Total section	2	6½
Total lignite	2	6

Location 910. SE. ¼ sec. 13.

	Ft.	in.
Shale, brown.		
Lignite		9
Shale, carbonaceous		1
Lignite	1	4
Shale.		
Total section	2	2
Total lignite	2	1

Location 911. NE. ¼ sec. 13.

	Ft.	in.
Shale.		
Lignite	2	0
Shale.		

T. 21 N., R. 11 E.

The surface of T. 21 N., R. 11 E., is a high plateau dissected by numerous streams. The divide between the North and South forks of Grand River, forming a broad upland prairie, crosses the northern part of the township. To the south a series of steep scarps separate the upland from the wide valley of Duck Creek.

The Ludlow lignitic member of the Lance formation outcrops in the valleys to the south but is very poorly exposed. Lignite beds in this member were found at a few points but are too thin to warrant mapping. Above the Ludlow member and separating it from the Fort Union formation is the Cannonball marine member of the Lance, which does not contain any beds of lignite. About 150 feet of the lower part of the Fort Union formation outcrops in the higher part of the township. Yellow sandstone is the most prominent rock in this part of the formation and outcrops on the steep sides of the hills, but there is also a considerable amount of shale, concealed for the most part by the mantle of soil on the smoother slopes.

The lignite bed that is mined near Lodgepole, in T. 21 N., R. 12 E., underlies the top of a high butte in secs. 9 and 10 of this township. At the east end of the butte (location 914, see Pl. X) it has been prospected to some extent. It is 6 feet thick, but as it is under only a few feet of cover it is weathered and the top part is mixed with sand. At the west end of the butte (location 913) the bed is under a better cover, but is thinner and contains partings of bone. The same bed is exposed in a butte at location 912, in the SE. ¼ sec. 18, where it is much thinner. The sections exposed at these places are shown graphically on Plate X. A few feet below the lignite bed is a persistent bed of very hard quartzitic rock, the residual blocks of which are thickly scattered over many of the higher buttes in this and adjoining townships. This bed is well exposed below the lignite bed at location 912, in sec. 18.

T. 22 N., R. 11 E.

The surface of T. 22 N., R. 11 E., is an irregularly rolling prairie, sloping gradually upward from the valley of the North Fork of Grand River, in the northern part of the township, to the plateau about the head of Lodgepole Creek, in the southeast corner. The outcropping rocks belong to the Ludlow lignitic and Cannonball marine members of the Lance formation and the lower part of the Fort Union formation. The two members of the Lance occupy the lower land in the northern part of the township and are concealed by the mantle of soil except at a few places. The contact of these two members and that between the Cannonball member and the Fort Union formation are effectually obscured, and the mapping is based on topographic data.

Lignite in the Ludlow member of the Lance is exposed at locations 918 and 917, in secs. 4 and 7, and is said to have been found in a well at location 916, in sec. 18. The beds at these localities are presumably at about the same horizon. The sections measured or reported at these places are as follows:

Sections of lignite beds in the Ludlow lignitic member of the Lance formation in T. 22 N., R. 11 E.

Location 916. NE. ¼ sec. 18.

	Ft.	in.
Lignite (reported in a well)	2	0

Location 917. SW. ¼ sec. 7.

	Ft.	in.
Lignite, burned.		
Shale, gray, sandy	9	0
Lignite		6

Location 918. SE. ¼ sec. 4.

	Ft.	in.
Shale.		
Sandstone, clayey	3	6
Lignite	1	8
Bottom of bed under water.		

No lignite beds were found in the lower 150 feet of the Fort Union, which consists chiefly of loosely cemented sandstone, but three small buttes in sec. 36 are underlain by the same bed that is being mined in the higher buttes near Lodgepole in T. 21 N., R. 12 E. In the western part of these buttes (location 915) the bed has a thickness of 5 feet 4 inches, with 1 inch of shale 1 foot 2 inches above the base, and is overlain by about 15 feet of sandstone and shale.

T. 23 N., R. 11 E.

The greater part of T. 23 N., R. 11 E., is occupied by the broad valley of the North Fork of Grand River, which flows eastward across the southern part of the township. The valley is separated by steep bluffs from the upland areas that extend northward from the State line at the north side of the township.

Fairly good sections of a part of the Ludlow lignitic member of the Lance formation are exposed in the bluffs of the river, but in the greater part of the township the underlying rocks are concealed by the mantle of soil. The Ludlow member is overlain by the Cannonball marine member of the Lance, and this in turn by the Fort Union formation, which outcrops in the steep hills in the northern part of the township and underlies the plateau farther north.

A thin bed of lignite in the Ludlow member of the Lance was examined at four places on the south side of the river, where it shows a range in thicknesss from 9 inches to 1 foot 5 inches. The sections are as follows:

Sections of a lignite bed in T. 23 N., R. 11 E.

Location 919. SW. ¼ sec. 31.

	Ft.	in.
Shale, light brown, sandy.		
Lignite	1	5
Shale, brown, sandy.		

Location 920. SE. ¼ sec. 32.

	Ft.	in.
Shale.		
Lignite, poor		9
Shale.		

Location 921. SW. ¼ sec. 34.

	Ft.	in.
Lignite		10

Location 922. SE. ¼ sec. 34.

	Ft.	in.
Lignite	1	5

T. 16 N., R. 12 E.

North of Antelope Creek, which crosses the southern part of T. 16 N., R. 12 E., in a meandering course, the surface rises gradually to the rather prominent divide near the northern part of the township. The underlying rocks are largely obscured by soil, which has been formed by the disintegration of the soft clay shale of the Lance formation. The crest of the divide, in secs. 11 and 12, is capped by a few feet of the Ludlow lignitic member of the Lance. On account of the poor soil little or no attempt has been made to cultivate the land. No lignite bed of any value is known to outcrop in the township.

T. 17 N., R. 12 E.

Rabbit Creek crosses T. 17 N., R. 12 E., near its southern border in a deeply intrenched meandering channel, and receives all the drainage of the township. The surface is gently undulating and for the most part grass-covered, although there are numerous small areas of almost barren land along the valleys. The survey for a branch of the Chicago, Milwaukee & St. Paul Railway passes through the town of Daviston, in sec. 9.

The Lance formation underlies the whole area, the Ludlow lignitic member occupying the highlands in the northern part. The soil produced by the disintegration of the soft clay shale of the lower part of the Lance is not especially fertile, and there are many small areas which are destitute of vegetation and unattractive to the farmer. Rock exposures are very scarce, but from such data as could be obtained it is assumed that the formations dip northward about 20 feet to the mile.

At the base of the Ludlow lignitic member of the Lance formation there is a bed of lignite which is being mined at the Graff mine, in sec. 11, and the Rogers and Sexton mines, in the township to the east. The Graff mine (location 925) was opened in 1910 and consists of an open strip pit, from which several loads of lignite had been sold to the farmers. The bed, as indicated by section 925 on Plate XI, is composed of two benches of lignite separated by a shale parting 1 foot 2 inches thick, and it is overlain by a cross-bedded sandy shale. The lignite bed is irregular in thickness, and measurements in the workings of the mine show the upper bench to vary from 6 to 11 inches within a distance of about 20 yards. At location 926, in sec. 24, a bed occurring at the base of the Ludlow lignitic member is composed of five thin benches of lignite separated by shale partings 1 inch to 9 inches thick. The lowest and thickest bench contains 2 feet 2 inches of good lignite.

Two other sections of unimportant lignite beds were measured in the township as follows:

Sections of lignite beds in T. 17 N., R. 12 E.

[In addition to those shown on Pl. XI.]

Location 923. NE. ¼ sec. 8.

	Ft.	in.
Shale, blue	1	
Lignite		6
Shale, brown.		
Total section	1	6
Total lignite		6

Location 924. NE. ¼ sec. 9.

	Ft.	in.
Sandstone, soft, yellow.		
Lignite	1	2
Shale, brown		2
Lignite		4
Shale, brown.		
Total section	1	8
Total lignite	1	6

T. 18 N., R. 12 E.

The surface of T. 18 N., R. 12 E., lies in the gently undulating prairie of the Big Meadow, and exposures of rock are scarce. Thunder Butte Creek crosses the meadow from west to east in the northern part of the township and occupies a very wide, flat valley, below the level of which its meandering channel has been cut only slightly.

A small area of the White River formation is present on the top of the hill in sec. 21. Elsewhere the Ludlow lignitic member of the Lance formation constitutes the surface rock. To judge from the few exposures along the creeks, the rocks dip a little east of north at about 18 feet to the mile.

At location 927, in sec. 32, a bed of lignite reported to be 3 feet thick has been mined by stripping. No accurate measurements of the bed could be made, for when visited it was covered by water.

T. 19 N., R. 12 E.

The surface of T. 19 N., R. 12 E., is rough, being in the area north of the Big Meadow known locally as The Breaks. Between the high meadow in secs. 30, 31, and 32 and the valley of the South Fork of Grand River in secs. 1 and 2 there is a difference in altitude of nearly 300 feet. Several rather deep, steep-sided valleys cross the township and carry the run-off to Grand River. Exposures of rock are fairly good, although the area is generally grass-covered.

The Lance formation is the surface rock, the lower part of the formation being exposed in a narrow area along the South Fork of Grand River and the Ludlow lignitic member underlying all the higher land. The rocks dip toward the northeast at about 14 feet to the mile.

Several lenticular beds of lignite in the Ludlow lignitic member of the Lance formation outcrop in the township, but only one is of sufficient thickness to be considered commercially important. This bed is exposed in secs. 18 and 19 and is thought to be the same as the one mined at location 820 in the township to the west. Sections 828 and 829 (Pl. XI) show a thickness of 3 feet 3 inches and 3 feet, respec-

tively. Thin beds of lignite outcrop in other parts of the township, and the following sections were measured at the places shown on the map:

Sections of lignite beds in T. 19 N., R. 12 E.

[In addition to those shown on Plate XI.]

No. on Pl. II.	Location.	Section.	Ft.	in.	No. on Pl. II.	Location.	Section.	Ft.	in.
830	NW. ¼ sec. 17	Soil.			832	NW. ¼ sec. 8	Shale, brown.		
		Shale, brown	1	10			Lignite	2	3
		Lignite	2	9			Shale, brown.		
		Shale, brown.							
		Total section	4	7	833	SE. ¼ sec. 33	Lignite	1	6
		Total lignite	2	9	834	SW. ¼ sec. 24	do	1	8
831	SW. ¼ sec. 8	Shale, brown	5	0					
		Lignite	1	0					
		Shale, brown.							
		Total section	6	0					
		Total lignite	1	0					

No prospecting or mining has been done in this township.

T. 20 N., R. 12 E.

The South Fork of Grand River flows eastward across the southern part of T. 20 N., R. 12 E., and on both the north and the south its valley is bordered by a series of terraces.

The strata are in places well exposed in the bluffs of the river and of the smaller streams, so that in the township an almost complete section of the outcropping rocks may be examined. These rocks belong to the lower part of the Lance formation, the Ludlow lignitic member, the Cannonball marine member, and the lower part of the Fort Union formation. The Ludlow member, which occupies the greater part of the area, consists of alternating beds of yellow sandstone, brown shale, clay, and lignite. The upper 20 or 30 feet of the lower part of the Lance appears above the level of the river, and the Cannonball marine member and the lower sandstone of the Fort Union outcrop in the northern part of the township.

Lignite beds are numerous in the Ludlow member, which is exposed in the river bluffs, but the beds are lenticular and in only a few places have a thickness of over 2 feet. Probably the thickest bed outcrops in a few isolated buttes in the northern part of the township, where it has a thickness of about 2 feet 6 inches.

T. 21 N., R. 12 E.

T. 21 N., R. 12 E., lies on the upland between the North and South forks of Grand River. Lodgepole Creek flows southeastward across the township in a wide, flat valley which is bordered on both the north and the south by high rocky ridges, rising above the general plateau surface. The town of Lodgepole is in sec. 8.

Rocks of the Fort Union formation, about 200 feet in maximum thickness, outcrop in the greater part of the township, but the Cannonball marine member of the Lance formation occupies the valley of Lodgepole Creek, in the eastern part, and the lower portions of valleys of the small streams that flow toward the south. Two massive partly consolidated beds of sandstone give rise to the most prominent topographic features, the upper one capping the high ridges in the northern and central parts of the township, and the other, about 60 feet lower, capping numerous lower buttes in the eastern part.

The principal lignite bed of this part of the field lies about 20 feet above the lower of these two sandstones and probably 100 feet above the base of the Fort Union. It underlies the two principal ridges and a few outlying buttes. The southern ridge extends eastward from secs. 18 and 19 to sec. 15. Two local mines are in operation on the south side of this ridge, one in the SE. ¼ sec. 19 and the other, the Nelson (location 937), in the NW. ¼ sec. 29. Both are drift mines from which only a small amount of lignite is mined in summer but a much larger amount in fall and winter. A sample (No. 14354) was collected from the Nelson mine for analysis, the results of which are shown in the table on page 43. The thickness of the bed in this part of the township (sections 937, 938, and 939, Pl. X) ranges from 6 feet 2 inches to more than 7 feet. At location 940, on the north side of the ridge in sec. 18, the bed is 5 feet 7 inches thick but contains several thin partings of bone. Farther east the outcrop is concealed by the mantle of soil and the bed has not been found. An outlying butte at the corner of sec. 22, 23, 26, and 27 is also grass-covered, so that the outcrop of the lignite bed is concealed.

The northern ridge extends southeastward from secs. 4 and 5 to sec. 11. The outcrop of the lignite bed is concealed on the south side of the ridge except at location 941, near the north quarter corner of sec. 5, where the bed has a thickness of 6 feet 1 inch, with thin partings of bone. On the north side of the ridge the bed has been examined at locations 942, 943, 944, and 945 in secs. 11, 2, 3, and 4, respectively. At location 945 the bed has been mined by stripping. The lignite bed is exposed at locations 946 and 948, in an isolated butte in the NW. ¼ sec. 1, where it is 4 feet 8 inches and 4 feet 4 inches thick, respectively. North of the butte a small block has slumped down about 50 feet and a partial measurement of the bed was made at location 947 in the slumped block. All these sections are shown graphically in Plate X.

T. 22 N., R. 12 E.

The North Fork of Grand River flows southeastward across the north-central part of T. 22 N., R. 12 E., in a wide, flat valley. Grand River post office is on the river in sec. 17. This valley is separated from the high uplands on the north and south by a series

of terraces. A high sandstone-capped ridge extends eastward nearly across the southern tier of sections.

The rocks that outcrop in this township belong to the Ludlow lignitic and Cannonball marine members of the Lance formation and the Fort Union formation. The total thickness of the Fort Union is approximately 200 feet. Near the top are two massive, partly consolidated beds of sandstone, forming the caps of numerous buttes which stand out conspicuously, particularly in the northeastern and southern parts of the township.

The only valuable bed of lignite in this part of the South Dakota field lies about 20 feet above the lower of these two sandstones and underlies the high hills in the southern part of the township and in the adjoining township on the south. The sides of the hills are very steep, in places precipitous, and the lignite bed can be easily uncovered with a shovel at almost any point desired. The bed was examined at four points along the main ridge—at location 949, in the SW. ¼ sec. 36; at locations 950 and 952, in the SW. ¼ sec. 35; and at location 954, in the SW. ¼ sec. 34, and similar measurements were obtained in small outlying buttes at location 951, in the SE. ¼ sec. 34; at location 955, in the NE. ¼ sec. 33; and at location 958, in the SW. ¼ sec. 31. Small drift mines have been opened and lignite removed for local use at location 953, in the SE. ¼ sec. 35; at location 956, in the NW. ¼ sec. 33; and at location 957, in an outlying butte in the NW. ¼ sec. 32. The thickness of the bed, as shown by these measurements, ranges from 5 feet 4 inches to 8 feet 10 inches. The detailed sections are given on Plate X.

A thin bed of lignite in the Ludlow member of the Lance was examined in the river bluff at Grand River post office (location 959) and was observed but not studied at other places along the river. The section at this place is as follows:

Section of lignite bed at location 959, in the NW. ¼ NW. ¼ sec. 16, T. 22 N., R. 12 E.

	Ft.	in.
Sandstone.		
Shale, carbonaceous		8
Lignite	1	4
Shale, carbonaceous	1	4
Lignite		8
Sandstone, carbonaceous.		
Total section	4	0
Total lignite	2	0

T. 23 N., R. 12 E.

T. 23 N., R. 12 E., lies south of the divide between the North Fork of Grand River and Flat Creek. The plateau that stretches away to the north is separated in this township from the lower land on the south in some places by moderately steep scarps and elsewhere by smooth slopes.

The Ludlow lignitic and Cannonball marine members of the Lance formation outcrop in the deeper valleys; the sandstone and shale of the lower part of the Fort Union formation underlie the plateau region. The line separating the two members of the Lance formation is only approximate, inasmuch as the surface is heavily grass-covered and there are very few natural rock exposures.

A high ridge nearly covered with quartzitic bowlders extends from the east into sec. 24 and is underlain by a bed of lignite approximately 3 feet thick, which, however, is not exposed in this township. At a lower level in the NW. ¼ SE. ¼ sec. 24 a thin bed has been prospected to some extent at location 960, but its thickness is only 1 foot 1 inch.

T. 16 N., R. 13 E.

The surface of T. 16 N., R. 13 E., is deeply dissected by Rabbit and Antelope creeks, and because of the easily weathered character of the rocks only a few good exposures occur. Rabbit Butte, in sec. 7, rises 100 feet or more above the surrounding country and is a conspicuous landmark. Soil derived from the clay shale of the Lance formation does not make good farm land, and consequently there are only a few small areas which have been cultivated, much of the land being almost barren of vegetation.

With the exception of a small area of the Ludlow lignitic member of the Lance formation in Rabbit Butte, the surface of this township is composed of the somber-colored shale of the lower part of the Lance, which here is not lignite-bearing. Two thin beds of lignite near the base of the Ludlow member are exposed in Rabbit Butte and are shown in the following section:

Section at Rabbit Butte, location 961, T. 16 N., R. 13 E.

	Ft.	in.
Shale, brown.		
Lignite	2	2
Shale, brown	25	0
Lignite	1	5
Shale, brown.		
Total section	28	7
Total lignite	3	7

T. 17 N., R. 13 E.

Rabbit Creek crosses sec. 31, T. 17 N., R. 13 E., and with its two main southward-flowing tributaries drains the entire township. The surface slopes gradually upward from the level of the creek to the meadow land at the northern boundary. It is rolling and grass-covered, and exposures of rock are scarce. The soil in most of the township is the result of the disintegration of the soft sandstone of the Ludlow lignitic member of the Lance formation. It is fertile, and numerous small farms are being cultivated.

The somber-colored shale of the lower part of the Lance formation outcrops in the southern part of the township, and the sandy shale and sandstone of the Ludlow lignitic member underlie the higher northern part.

At the base of the Ludlow member there is a bed of lignite which in the vicinity of the Rogers and Sexton mines is thick enough to be of economic importance. To the east and west, however, along its outcrop the bed is worthless, being split into several benches at location 926, in sec. 24, of the township to the west. (See p. 140.) At location 966 (see Pl. XI), in sec. 29, the bed is represented by only 2 feet 2 inches of lignite split into two benches.

The Rogers mine at location 962, in sec. 18, is an open strip pit from which a large amount (probably several hundred wagon loads) of lignite has been mined by stripping off the 15 to 20 feet of overburden with a scraper. The mine has been operated for several years, supplying a large local demand. The lignite is bright, hard, and nearly black and has fairly well developed cleavage planes. Numerous aggregations of iron pyrite are present along the joint planes of the bed. The part of the bed mined is 5 feet thick.

The Sexton mine, at location 964, about half a mile to the east, on the same bed, which at this place has a thickness of 4 feet 11 inches, is worked by the same method, and the lignite is sold locally. This mine has been opened more recently than the Rogers mine, but nevertheless several hundred wagon loads of fuel have been removed from it.

South and east of the mines the bed is burned along its outcrop, but it can be traced easily by the resulting red soil and rock. Sections 962 to 967 (Pl. XI), which were measured in this township, illustrate the irregularities of the lignite bed occurring at the base of the Ludlow member in this part of the field.

T. 18 N., R. 13 E.

The greater part of the surface of T. 18 N., R. 13 E., is rolling meadow or farm land. The maximum difference in altitude between the lowest valley land and the highest butte is not much more than 100 feet. Thunder Butte Creek drains almost the entire township, passing across it a little south of the center in a broad, flat valley, the sides of which constitute the low dividing ridge between the South Fork of Grand River on the north and Rabbit Creek on the south. The area is largely under cultivation, inasmuch as the soil, which is derived mainly from the sandy beds of the Ludlow lignitic member of the Lance formation, is very fertile. Bison, the county seat of Perkins County, is a thriving town of 100 or more people in sec. 13.

Along the southern margin of the township the lower part of the Lance formation is exposed in a small area. Elsewhere the surface

rocks belong to the Ludlow member. No bed of lignite is known to outcrop in the township, and no valuable bed has been found in the wells of the area.

T. 19 N., R. 13 E.

The South Fork of Grand River crosses T. 19 N., R. 13 E., near its northern boundary and receives drainage from the entire area. To the south the surface rises about 480 feet in very rugged slopes to the altitude of the Big Meadow. Several well-defined valleys heading along the southern margin of the township cross it in a northerly direction, at nearly right angles to the valley of the South Fork of Grand River. North of the river the surface rises abruptly, especially near Breckenridge post office, where the river flows very close to a cliff that reaches a height of nearly 100 feet above the valley. Little farming has been done in the area because the surface is too rough. Although the surface is largely grass-covered, there are numerous exposures from which to study the bedrock.

A narrow area in the valley of the South Fork of Grand River is underlain by the lower part of the Lance formation (see Pl. II), but the Ludlow lignitic member of the Lance occupies the major part of the township. The strata dip very slightly northeastward.

Two small strip mines on a bed of lignite which outcrops in secs. 27, 28, 33, and 34 have been opened by the farmers of the vicinity to supply their own needs, but, as indicated by sections 968 and 969 (Pl. XI), taken at the mines, the thickness of the bed at neither place is sufficient to warrant extensive mining. Thin lignite beds are exposed at several other places but have not been mined or prospected. The lignite bed at the base of the Ludlow member is exposed at locations 972 to 974, but at no place is there a sufficient thickness to make mining attractive.

Sections of lignite beds in T. 19 N., R. 13 E.

[In addition to those shown on Pl. XI.]

No. on Pl. II.	Location.	Section.	Ft.	in.	No. on Pl. II.	Location.	Section.	Ft.	in.
970	SW. ¼ sec. 25..	Soil.			972	NW. ¼ sec. 5..	Clay, sandy.		
		Lignite.........	2	0			Lignite.........		8
971	SE. ¼ sec. 26..	Shale, brown.					Shale, brown........	2	10
		Lignite.........	2	6			Lignite.........	2	6
		Shale, drab.........	5				Total section.	6	0
		Lignite.........	1	2			Total lignite..	3	2
		Shale, brown.							
		Total section.	8	8	973	NE. ¼ sec. 10..	Lignite.............		10
		Total lignite..	3	8	974	NE. ¼ sec. 11..	Lignite.............	1	1

T. 20 N., R. 13 E.

The low grass-covered divide that crosses near the center of T. 20 N., R. 13 E., in an easterly direction separates the drainage of the South

Fork of Grand River on the south from that of Lodgepole Creek on the north. On either side the surface slopes gradually away from the divide and is traversed by broad valleys. A large proportion of the surface is under cultivation, and good rock exposures are very scarce.

The surface rocks belong to the Ludlow lignitic and Cannonball marine members of the Lance formation and the Fort Union and White River formations. The White River occupies a small area on top of the divide in sec. 16. The boundaries of the other formations, as shown on the map (Pl. II), are drawn only approximately.

No bed of lignite of any value is known in the township, but beds less than 4 inches thick are reported to have been found in a number of wells south of Cole post office.

T. 21 N., R. 13 E.

The upland between Lodgepole Creek and the North Fork of Grand River extends from the western border of T. 21 N., R. 13 E., nearly across the township. The plateau has been largely dissected by the two streams and their numerous tributaries.

The rocks that outcrop in the township belong to the Cannonball marine member of the Lance formation and the Fort Union formation, but no attempt was made in the field to map the contact between the two, and the line shown on the map is therefore only approximate. A massive, partly consolidated bed of sandstone in the Fort Union forms the caps of a number of prominent buttes that rise above the general plateau level in the western part of the township. The surface of the township is for the most part grass-covered, and natural exposures are few except in the bluffs of the North Fork of Grand River, which flows eastward across the northeast corner of the township.

No lignite beds were found or reported in this township.

T. 22 N., R. 13 E.

A group of high rocky hills occupies the central part of T. 22 N., R. 13 E., rising conspicuously above the valley of the North Fork of Grand River, which flows southeastward across the southwestern part of the township. To the north the rocky hills give way to a high rolling prairie.

The rocks that outcrop in this township belong to the Ludlow lignitic and Cannonball marine members of the Lance formation and the lower part of the Fort Union formation. The steep bluffs of the North Fork of Grand River furnish good exposures of parts of the Ludlow and Cannonball members, and a prominent bed of sandstone in the Fort Union forms the caps of the prominent buttes. With

these exceptions, the underlying rocks are for the most part concealed by a heavy mantle of soil.

A bed of lignite which is correlated with the bed that is being mined near Lodgepole, S. Dak., and north of Haynes, N. Dak., underlies three small buttes in secs. 1 and 2. At location 975, in sec. 2 (see Pl. X), which is the only point where the bed is exposed, it has a thickness of 2 feet 6 inches. The horizon of this bed is above the tops of the hills in the central part of the township.

T. 23 N., R. 13 E.

The surface of T. 23 N., R. 13 E., is a rolling upland prairie, dissected by numerous small valleys. The rocks that outcrop in the township belong to the Fort Union formation and are fairly well exposed along the valleys in the western part of the township. In the northeast a partly consolidated bed of sandstone forms the caps of numerous low hills that rise abruptly from the nearly flat valleys. A high rocky ridge extends westward from sec. 21 of this township into sec. 24, T. 23 N., R. 12 E., and is underlain by a bed of lignite which is correlated with the bed that is being mined near Lodgepole, S. Dak., and north of Haynes, N. Dak. In this township the bed has been mined to some extent by stripping at location 976 in the SW. ¼ sec. 19, and at location 977, in the SW. ¼ sec. 21, where the bed has a total thickness of 3 feet 4 inches and 5 feet 3 inches, respectively. (See Pl. X.) At location 977 the bed is split into four benches by shale and bone partings. The same bed underlies an isolated butte in secs. 33 and 34, but the outcrop is covered by the mantle of soil.

T. 16 N., R. 14 E.

The surface in T. 16 N., R. 14 E., is moderately dissected by small streams and only partly covered with grass. Soil resulting from the disintegration of the soft argillaceous shale that forms the surface rock does not make good farm land, hence very few farmers have settled in the area. The lower part of the Lance formation, which underlies this area, contains no lignite in this part of the field.

T. 17 N., R. 14 E.

The valleys of Thunder Butte Creek and its main tributary, Lone Tree Creek, constitute a large part of T. 17 N., R. 14 E. Away from the streams the surface rises gradually in a grass-covered slope to a maximum altitude of less than 100 feet above the level of the valley floors. Numerous farmers have recently taken up land in this part of the State, but continued drought has produced discouraging results and many of them have already been forced to abandon their claims and leave the country. Although there are small areas in which the soil will produce good crops when properly cared for, a large part of

the township is destined to remain uncultivated. Except for a thin covering of the Ludlow lignitic member of the Lance formation on a few of the higher areas, the surface rocks belong to the lower part of that formation and dip northward at about 20 feet to the mile.

A single bed of lignite is exposed along Thunder Butte Creek in sec. 3, where the following section was measured:

Section of lignite bed at location 978, in sec. 3, T. 17 N., R. 14 E.

	Ft.	in.
Shale, drab	2	6
Lignite	2	8
Shale, drab.		
Total section	5	2
Total lignite	2	8

T. 18 N., R. 14 E.

T. 18 N., R. 14 E., lies in the meadow area, and its surface is accordingly only very slightly dissected. The maximum difference in altitude between the valley of Thunder Butte Creek, on the southwest, and the conspicuous buttes in the northeastern part of the township is probably less than 150 feet, and over most of the area there is a difference of less than 50 feet. There are a large number of well-established farms in the township, and only a small proportion of the land has not been put under cultivation. Five small white buttes in the northeastern part of the township rise about 50 feet above the average level of the meadow and stand out as conspicuous landmarks in a generally flat, grass-covered region.

Rocks of the lower part of the Lance formation crop out along Thunder Butte Creek, in the southwest corner, and are overlain with apparent conformity by the sandy Ludlow lignitic member of the Lance formation, which occupies the surface of nearly all the remainder of the area. The maximum thickness (200 feet) of the Ludlow in this township is represented in the northeastern part. The five prominent buttes are formed by about 45 feet of clay and sandstone of the White River formation from which fossils of Oligocene age were obtained. (See Pl. IV, *A*, p. 32.)

Exposures of rock in this township are very rare, and neither they nor the available well records indicate the presence of valuable lignite beds in this part of the field.

T. 19 N., R. 14 E.

The surface of T. 19 N., R. 14 E., is deeply dissected by several nearly parallel valleys, and most of the area is not suitable for farming. Between the South Fork of Grand River and the top of the small white butte in sec. 34 there is a difference in altitude of nearly 450 feet. Although the surface is rough, a mantle of soil covers most of it and obscures the rock structure.

A considerable area in the valley of the South Fork of Grand River is occupied by the shale of the lower part of the Lance formation, but the rest of the township is covered by rocks of the Ludlow lignitic member of the Lance, with the exception of a small prominent butte in sec. 34, which is capped by 45 feet of clay of the White River formation. The rocks dip gently to the north.

There are practically no exposures of the lignite except where farmers have uncovered the beds to procure their fuel supply. Sections 979 and 981 to 986, Plate XI, were measured in small mines. None of the mines have been developed on a large scale, but each has furnished several wagon loads of fuel. The mining has been done by stripping the rock overburden, in places as much as 15 feet, and then digging up the lignite. Above the lignite at the small mine at location 982, sec. 35, there is about 150 feet of overburden, so that future mining here will have to be done from drift openings. The beds mined range in thickness from 1 foot 1 inch at location 985, in sec. 6, to 2 feet 3 inches at location 982, in sec. 35. The section given below was measured near the top of a high hill in sec. 32, on what is assumed to be the same bed as that opened at location 981, in sec. 30:

Section of lignite bed at location 980, in sec. 32, T. 19 N., R. 14 E.

	Ft.	in.
Shale, brown.		
Lignite	1	3
Sandstone, yellow		6
Lignite	1	5
Shale, brown.		
Total section	3	2
Total lignite	2	8

In the NE. ¼ NW. ¼ sec. 12 the outcrop of a bed reported to be about 1 foot thick is covered by gravel, but a near-by rancher has mined a small amount of lignite by stripping off the gravel.

T. 20 N., R. 14 E.

The South Fork of Grand River occupies a broadly meandering course in the wide valley in secs. 25 and 36, T. 20 N., R. 14 E. Near the valley the slopes are abrupt, but elsewhere in this township the surface is a rolling grass-covered prairie. Several well-developed valleys cross the township from west to east but do not contain running water for any large part of the year. Lodgepole Creek, which crosses the township near the northeast corner, follows a meandering course in a rather narrow valley. A large portion of the land is under cultivation and makes very good farm land.

Rocks belonging to the Ludlow lignitic and Cannonball marine members of the Lance formation and dipping northward at low angles form the surface of nearly the entire township. The lower part of the

Lance is exposed in small areas along the South Fork of Grand River in the southeastern part and along Lodgepole Creek in the northeast corner.

A thin bed of lignite occurs at the base of the Ludlow member in the northern part of the area and has been mined at a small strip mine at location 989, in sec. 1, where it is only 2 feet 6 inches thick. Two beds of lignite are exposed in sec. 13, as follows:

Sections of lignite beds in T. 20 N., R. 14 E.

[In addition to those shown on Pl. XI.]

Location 987.

	Ft.	in.
Sandstone, yellow, soft.		
Lignite, with pyrite	2	5
Shale, carbonaceous		4
Lignite		3
Shale.		
Total section	3	0
Total lignite	2	8

Location 988.

	Ft.	in.
Shale, yellow.		
Lignite	1	8
Shale, brown.		

T. 21 N., R. 14 E.

From the divide near the center of T. 21 N., R. 14 E., the land slopes rather abruptly to the North Fork of Grand River on the north and Lodgepole Creek on the south, both of which are perennial streams. The surface, though generally grass-covered, is dissected by numerous small streams but is not so rough as to prevent cultivation. Good wagon roads follow nearly all the section lines and provide avenues along which produce may be hauled to the Chicago, Milwaukee & St. Paul Railway, which is about 15 miles to the north. Settlers who have taken up land in this part of the State have been fairly successful in raising crops of small grains, potatoes, etc.

Shale of the lower part of the Lance formation is exposed along the valleys of Lodgepole Creek and the North Fork of Grand River, but the surface of the greater part of the township is composed of the soft sandstone and sandy shale of the overlying Ludlow lignitic and Cannonball marine members of the Lance.

Two thin lignite beds outcrop near the base of the Ludlow member at location 990, in sec. 11, where the following section is exposed:

Section of lignite beds at location 990, sec. 11, T. 21 N., R. 14 E.

	Ft.	in.
Clay.		
Lignite	1	6
Interval	50	0
Lignite	1	2
Shale, brown		7
Lignite		10
Shale, brown.		
Total section	54	1
Total lignite	3	6

The outcrop of neither of the beds could be followed beyond the single cut bank, and the beds are therefore supposed to represent local lenses.

No mining has been done in this particular area, but it is probable that the 3 foot 4 inch bed of lignite which is mined at the Brady mine, in sec. 6 of the township to the southeast, may underlie a portion of sec. 36 of this township and possibly may be mined there in the near future.

T. 22 N., R. 14 E.

The surface of T. 22 N., R. 14 E., is an irregularly rolling prairie with numerous small valleys and a few prominent buttes. White Butte, a conspicuous landmark in secs. 21 and 28, is capped with nearly white sandstone, probably a part of the White River formation. The rocks underlying the remainder of the township belong to the Cannonball marine member of the Lance formation and the Fort Union formation. A partly consolidated bed of sandstone in the Fort Union forms the caps of a few prominent buttes and outcrops high on the sides of White Butte. A bed of lignite about 20 feet above this sandstone underlies White Butte and another prominent butte in sec. 15. The bed has been mined from a drift at the south end of the latter butte (location 992), but at the time the township was examined, in June, 1912, the lignite in the mine was burning and the mine had been closed. The section measured at the mouth of the mine contains a total of 6 feet 4 inches of lignite, but on White Butte, where considerable prospecting has been done, the bed contains a large proportion of shale. The detailed sections (991 and 992) are shown on Plate X.

T. 23 N., R. 14 E.

The surface of T. 23 N., R. 14 E., is a rolling prairie, interrupted by a number of high rocky buttes in the western part. The main line of the Chicago, Milwaukee & St. Paul Railway crosses the north border of the township. White Butte post office is on that line in sec. 3. The outcropping rocks belong to the Cannonball marine member of the Lance formation and the Fort Union formation but are for the most part concealed by a heavy mantle of soil. A partly consolidated sandstone in the Fort Union forms the caps of the prominent buttes in the western part of the township. No lignite was found or reported in this township.

T. 16 N., R. 15 E.

A rather pronounced grass-covered plateau-like divide, separating the drainage of Thunder Butte Creek on the north from that of Rabbit Creek on the south, crosses T. 16 N., R. 15 E., from northwest to southeast and rises more than 100 feet above the valley levels. On each side of this upland, where the soil is the result of the disinte-

gration of the clay shale of the lower part of the Lance formation, there are numerous small areas of barren, unattractive land. Nevertheless, a number of small farms have been located in the valley of Thunder Butte Creek. The surface south of the divide descends in a rather steep, intricately dissected, and nearly barren slope toward Rabbit Creek. Chance, a small but thriving town, is a short distance north of this township and is the market place for the inhabitants of this vicinity.

From 30 to 60 feet of beds belonging to the Ludlow lignitic member of the Lance formation are exposed in an area about a mile in width along the divide. At the base of the yellow sandy beds of the Ludlow member there is a bed of lignite which, although not of great value, has been prospected and mined at several places. At the Rail mine, location 997 in sec. 20 (see Pl. XI), the following section is exposed:

Section at Rail mine, in sec. 20, T. 16 N., R. 15 E.

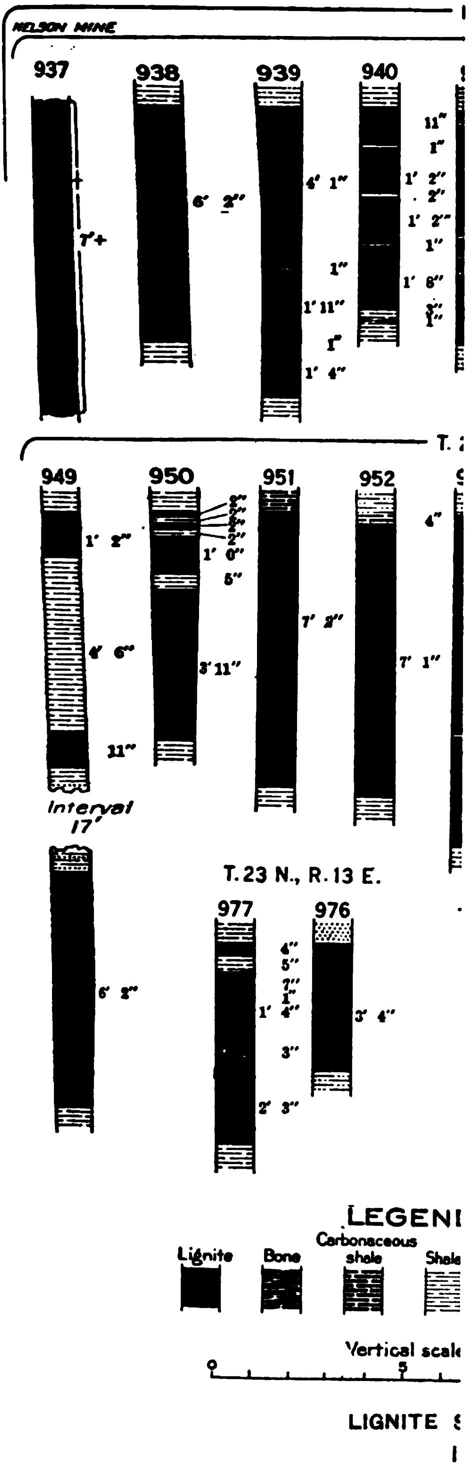
	Ft.	in.
Sandstone, yellow, soft, massive	4	0
Shale, yellow, argillaceous	3	0
Shale, drab	2	11
Shale, carbonaceous		7
Lignite		1½
Shale, drab		3
Lignite		9
Sandstone		½
Lignite	1	4
Shale, brown		7
Lignite		8
Shale, black.		
Total section	14	3
Total lignite	2	10½

The mine was opened in 1908 by Alexander Rail, and considerable lignite has been removed and sold to the near-by farmers at $3 a double box-wagon load. It has been possible so far to mine the lignite by stripping the comparatively thin cover, but as the overburden beyond the present workings is about 50 feet thick, it will be necessary to abandon the stripping method and resort to drifting.

The following is a detailed section of the same bed at the Wilson mine, at location 998, in sec. 21:

Stratigraphic section at the Wilson mine, at location 998, sec. 21, T. 16 N., R. 15 E.

	Ft.	in.
Clay, pink, shaly	1	6
Sandstone and shale, yellow, sandy	5	0
Shale, drab	3	6
Shale, carbonaceous		7
Lignite		1½
Shale, drab		3


NELSON MINE
937
938
939
940
7'+
6' 2"
4' 1"
1"
1' 11"
1"
1' 4"
11"
1"
1' 2"
2"
1' 2"
1"
1' 8"
2"
1"
T. 2
949
950
951
952
1' 2"
4' 6"
11"
2"
2"
2"
2"
1' 0"
5"
3' 11"
7' 2"
4"
7' 1"
Interval 17'
6' 2"
T. 23 N., R. 13 E.
977
976
4"
5"
7"
1"
1' 4"
3"
2' 3"
3' 4"
LEGEN
Lignite
Bone
Carbonaceous shale
Shale
Vertical scale
0
5
LIGNITE

	Ft.	In.
Lignite		10
Sandstone		½
Lignite		9
Shale, brown, with lenses of lignite		5
Lignite		2
Shale, drab, sandy		5
Lignite		7
Shale, black.		
Total section	14	2
Total lignite	2	5½

This is a small strip mine opened in 1908 to supply the needs of the owner, and little if any lignite has been sold. The present workings have necessitated the stripping of only a small amount of overburden, but further development will probably require drifting, as beyond these workings the overburden is from 40 to 50 feet thick.

The same bed of lignite has been mined on a small scale in sec. 27, where the section is as follows:

Section of lignite bed at location 1000, sec. 27, T. 16 N., R. 15 E.

	Ft.	In.
Shale, yellow, sandy.		
Lignite	1	6
Lignite, poor, bony		6
Shale, brown.		
	2	0

The mine, being located near the head of a narrow, steep-sided gulch, is not easily accessible and therefore will probably not be much further developed.

The following sections of the same bed are exposed at the locations shown on the map but are not shown graphically on Plate XI:

Sections of lignite bed in T. 16 N., R. 15 E. (in addition to those shown in Pl. XI).

No. on Pl. II.	Location.	Section.
993	SW. ¼ sec. 17	Shale, brown. Ft. in. Lignite 2 2
994	NW. ¼ sec. 20	Shale, brown. Lignite......... 1 5 Shale, brown.... 8 Lignite......... 3 Shale, brown. Total section.. 2 4 Total lignite.. 1 8
995	NW. ¼ sec. 20	Shale, drab. Lignite......... 9 Shale, brown, sandy......... 1 5 Lignite......... 3 Shale, brown.... 4 Lignite......... 2 Shale, brown. Total section.. 2 11 Total lignite.. 1 2
996	NW. ¼ sec. 20	Shale, drab. Ft. in. Lignite......... 10 Shale, drab..... 2 Lignite......... 8 Shale, brown. Total section.. 1 8 Total lignite.. 1 6
999	NE. ¼ sec. 17	Soil.............. 1 6 Lignite, weathered.......... 9 Shale, drab..... 1 8 Lignite......... 11 Shale, drab. Total section.. 4 10 Total lignite.. 1 8
1001	NW. ¼ sec. 34	Bone.............. 1 6

T. 17 N., R. 15 E.

Thunder Butte Creek crosses T. 17 N., R. 15 E., from west to east near the southwest corner in a very crooked meandering channel cut several feet below the average valley level. On each side the surface rises gradually in a grassy prairie broken here and there by rather sharp ridges or buttes. Chance, in sec. 28, although at present 45 miles from a railway, is one of the prosperous towns of the region. The line surveyed for the proposed extension of the Chicago, Milwaukee & St. Paul Railway from Firesteel passes within a short distance of the town and should the railway be constructed according to that survey, Chance will undoubtedly become a very important shipping point for grain and produce grown in The Meadow and surrounding area. The town is now connected with the railway at Lemmon, to the north, by daily stage through Meadow.

Most of the township is meadow or cultivated land, but there are a few exposures of rock along the streams. With the exception of the somber-colored shale of the lower part of the Lance formation in the valley of Thunder Butte Creek the surface rock belongs to the Ludlow lignitic member of that formation. The rocks appear to dip northwestward at about 13 feet to the mile.

Lignite is exposed at only two places in the township, neither of which have attracted the attention of prospectors. At location 1002, in sec. 20, there is a bed 1 foot 8 inches thick, and at location 1003, in sec. 17, there is a bed 1 foot 1 inch thick.

T. 18 N., R. 15 E.

The surface of T. 18 N., R. 15 E., is gently rolling meadow or farm land with only a few exposures of rock along the small streams. The soil is the result of the disintegration of the soft sandy shale and sandstone of the Ludlow lignitic member of the Lance formation and will produce good crops of small grains, potatoes, etc., when care is taken to make the best use of the 10 to 20 inches of annual rainfall. Meadow, one of the older towns of Perkins County, is in sec. 13 and is the distributing point for a large area in this part of the field. Mail for the surrounding country is brought to Meadow from Lemmon, 35 miles to the north, by daily automobile stage. Wagon roads of the best type are to be found along section lines in this part of the field.

Lignite is exposed at three places in the township. At location 1005, in sec. 11, a bed reported to be from 1 foot 2 inches to 1 foot 6 inches thick has been uncovered and several loads of lignite have been removed. At location 1006, in sec. 36, a bed 1 foot 8 inches thick with a 2-inch parting near the middle has been worked by the near-by farmers. At both mines the lignite was covered by water in September, 1911, and detailed sections could not be measured. At location 1004 the following section is exposed:

Section of lignite bed at location 1004, in the NE. ¼ sec. 10, T. 18 N., R. 15 E.

	Ft.	in.
Lignite		4
Shale, brown	1	11
Lignite	1	6
Shale, brown.		
Total section	3	9
Total lignite	1	10

T. 19 N., R. 15 E.

From the general level of the Big Meadow along the southern border of T. 19 N., R. 15 E., the surface slopes gradually in a northwesterly direction toward the South Fork of Grand River, which crosses the southern part of the township to the northwest. Two wide, open valleys traverse the township from southeast to northwest and receive most of the run-off from this part of the field. Although the surface is considerably broken by ridges and valleys, the soil is fertile enough to encourage cultivation, and at the time of examination, in 1911, a large number of small farms had been established in this and adjacent townships. Lemmon, the nearest railway town, on the Chicago, Milwaukee & St. Paul Railway, about 25 miles to the north, is the shipping point for this part of the field.

With the exception of small areas in the lowlands in the northwest corner, where the lower part of the Lance formation is exposed, the surface rocks of the township belong to the Ludlow lignitic member of the Lance. The lower rocks are soft clay shale and form a poor soil, but the sandy shale and soft sandstone of the overlying Ludlow lignitic member produce a fertile sandy loam which in most of the area is grass-covered or cultivated. Exposures of bedrock are scarce.

A bed of lignite at location 1009 (see Pl. XI), in sec. 4, at the base of the Ludlow member, has been mined by the farmers of the vicinity. From 8 to 10 feet of overburden was removed with a scraper in order to obtain the lignite.

Thin beds of lignite are exposed at two other localities in the township, but their outcrops could not be followed far beyond the places at which the sections were measured:

Sections of lignite beds in T. 19 N., R. 15 E.

Location 1007. Sec. 34.

	Ft.	in.
Shale, brown	1	9
Lignite		3
Shale, brown		6
Lignite		3
Shale, brown	1	6
Lignite	1	11
Shale, brown.		
Total section	6	2
Total lignite	2	5

Location 1008. Sec. 6.

	Ft.	in.
Shale, drab.		
Lignite	1	2
Shale, carbonaceous		4
Shale, yellow, sandy.		
Total section	1	6
Total lignite	1	2

That the lignite beds described are not persistent is indicated by the fact that the bed exposed in sec. 34 is not present in a well 152 feet deep less than 1 mile to the southeast, where the surface is not more than 50 feet higher than that at location 1007.

T. 20 N., R. 15 E.

The South Fork of Grand River, which crosses T. 20 N., R. 15 E., from southwest to northeast, follows a meandering course in a valley about half a mile in width, along each side of which are terraces standing about 30 feet above the present river channel. Beyond the terraces the surface rises in rugged hills to a maximum height of more than 200 feet above the river. Away from the sandy valley bottoms the land is in many places under cultivation, although the surface is too uneven to make ideal farm land. The route of the automobile stage between Lemmon and Meadow crosses the eastern part of the township.

The valley of the South Fork of Grand River and its tributaries is occupied by the somber-colored shale of the Lance formation; the highlands on each side are formed by the yellow sandstone and sandy shale of the Ludlow lignitic and Cannonball marine members of the Lance.

The only bed of lignite that outcrops in the township occurs at the base of the Ludlow member and has been mined at several localities. The Kirkland mine at location 1010 (see Pl. XI), in sec. 23, consists of a strip pit 80 by 30 feet, from which lignite has been mined and sold to near-by farmers. The lignite at this point is only 2 feet thick.

The Brady mine at location 1014, in sec. 6 (see Pl. XI), on the north side of Lodgepole Creek, was worked by stripping in October, 1911. About 150 wagon loads of lignite had been removed and sold to the farmers in the vicinity.

About the same amount of lignite had been taken from a mine a short distance to the east (location 1015), which when visited had been abandoned, probably because it had become necessary to strip about 35 feet of overburden in order to obtain lignite. The bed at this point is 3 feet 7 inches thick.

An area about 50 by 100 feet was mined out at a small strip opening at location 1013, in the SW. ¼, sec. 6, where the bed shows the following section:

Section of lignite bed at location 1013, in sec. 6, T. 20 N., R. 15 E.

	Ft.	in.
Shale, bluish, sandy.		
Lignite		2
Shale, bluish, sandy	2	2
Lignite	3	
Shale, dark brown.		
Total section	5	4
Total lignite	3	2

Measurements of the bed were taken at several other places, as follows:

	Ft.	in.
Location 1011, sec. 17	1	2
Location 1012, sec. 7	1	10
Location 1016, sec. 1		11
Location 1017, sec. 13	1	6

T. 21 N., R. 15 E.

The North Fork of Grand River flows across T. 21 N., R. 15 E., in a meandering channel cut 30 to 40 feet below the terrace level on either side and joins the main river in sec. 26, near the town of Seim. Away from the main terrace the surface rises in a grass-covered slope, broken here and there by small areas of rough topography in which the bedrock has been exposed by erosion. Many farmers have settled in the area and are meeting with some success in raising small grains. Seim, a small town in sec. 26 on the stage route between the railway at Lemmon and Meadow, to the south, has a single store and a creamery. Being less than 15 miles from the Chicago, Milwaukee & St. Paul Railway, to the north, the farmers of this area are within easy reach of a market for their produce.

The Ludlow lignitic member of the Lance formation is probably present in the southern part of the township, but in the northern part the Cannonball marine member of the Lance directly overlies the lower part of the formation. This part of the field was examined in detal prior to the differentiation of the Cannonball and Ludlow members, but it seems evident that in this general region the two grade laterally into each other.

A bed of lignite 2 feet 5 inches thick is exposed at the base of the Ludlow lignitic member at location 1017A (see Pl. XI), in sec. 32. It is probable that the bed of lignite which is mined at the Brady mine, in sec. 6 of the township to the south, is present beneath part of sec. 31 of this township.

TPS. 22 AND 23 N., R. 15 E.

The surface from the south boundary of T. 22 N., R. 15 E., northward to the North Dakota line, may be characterized as a prairie across which Flat Creek meanders in a broad, open valley. The difference in elevation between the lowest and highest points in this area is scarcely more than 100 feet. The sandy loam soil has attracted a large number of farmers, and at the time the field was visited a large part of the area was under cultivation. All the area is within easy reach of the Chicago, Milwaukee & St. Paul Railway, which skirts the region along the North Dakota State line.

The lower part of the Lance formation, the Cannonball marine member of the Lance, and the Fort Union formation are present in these townships. The contacts are very obscure, both on account

of the similarity of the rocks and on account of the grass-covered condition of the surface.

A single bed of lignite in the Fort Union formation crops out in sec. 25, T. 23 N., and two sections were measured. At location 1018 the bed is 1 foot 5 inches thick, and at location 1019 it is 1 foot 1 inch thick.

TPS. 16 AND 17 N., R. 16 E.

Thunder Butte Creek, which meanders across T. 16 N., R. 16 E., from west to east in a very narrow channel several feet below the average valley level, drains practically the entire area of this township and T. 17 N., R. 16 E. A large part of the broad valley on both sides of the creek is nearly barren of vegetation, owing to the low fertility of the soil, but north of the creek the soft sandstone and sandy shale which occupy the uplands yield a sandy loam, and as a consequence the surface where not cultivated is grass-covered and rock exposures are scarce. Coal Springs, the only town in this area, is one of the older towns of the region. Grass covers the surface of these townships, but the cut banks of streams furnish numerous exposures from which the structure and character of the rocks were determined.

The Lance is the surface formation of this area. The line between the Ludlow lignitic member of the Lance and the underlying rocks is extremely difficult to follow, but by a study of the soil, which in areas of the Ludlow is more sandy and yellowish than in areas where the somber-colored clay shale of the lower part of the formation occurs, the contact between the two parts of the formation can be determined.

The only exposure of lignite is in sec. 24, T. 17 N., where a thin bed crops out in the side of the valley, with the following section:

Section of lignite bed at location 1020 in sec. 24, T. 17 N., R. 16 E.

	Ft.	in.
Shale, yellowish, sandy		8
Lignite, poor		2
Shale, carbonaceous		6
Lignite, poor		8
Shale, brown.		
Total section	2	0
Total lignite		10

TPS. 18 AND 19 N., R. 16 E.

Tps. 18 and 19 N., R. 16 E., occupy a position along the eastern edge of the Big Meadow. The western part of each township is almost level, but around the margin of the typical meadow area the surface is broken and numerous small streams have their beginning. In the portions of the townships which were originally occupied by meadow lands there are a large number of well-established farms with good buildings, windmills, etc., and only a few uncultivated

tracts remain. In this area, as in the rest of the meadow country, good wagon roads are to be found along nearly every section line. Meadow, one of the principal towns of Perkins County, is in sec. 13, T. 18 N., R. 15 E., and is the distributing point for all the eastern part of the county, being connected with the Chicago, Milwaukee & St. Paul Railway, 35 miles to the north, by daily automobile stage.

The upland is formed of rocks of the Ludlow lignitic member of the Lance formation, and exposures are exceedingly scarce. In the eastern part of these townships where the surface rocks belong to the lower part of the formation, exposures are more numerous than elsewhere. To judge from data collected in these and adjacent townships, the dip of the rocks is northward at about 15 feet to the mile.

Near the contact between the two members of the Lance there are at different localities one or more beds of lignite that have been mined on a small scale. Anderson mine, located at the "Coal Springs," in sec. 35, T. 17 N. (location 1021; see Pl. XI), is one of the oldest coal openings in northwestern South Dakota, but only a comparatively small amount of lignite has been mined and sold, probably owing to the fact that the bed is badly split by shale partings. Todd,[1] in 1902, visited this part of the region and measured a section of the bed. East of the Anderson mine, in sec. 36, T. 17 N. (section 1022, Pl. XI), there is a small strip pit from which some of the farmers mined coal for their own use in 1910–11, but the bed here is of little value.

The Cooke mine, at location 1025, in sec. 15, T. 17 N., is an open-strip pit from which considerable lignite was being mined and sold to the near-by farmers in 1911. The bed at this locality is separated into three thin benches by thick partings of shale. (See section 145, Pl. XI.) Along the side of the valley about a quarter of a mile north of the Cooke mine the upper bed is slightly thicker, containing at location 1024 1 foot 6 inches of lignite. At location 1026, in sec. 4, T. 17 N., a small amount of lignite had been removed by stripping from a bed 1 foot 11 inches thick.

In sec. 25, T. 18 N., R. 16 E., is a lignite bed, of which the following section was measured:

Section of lignite bed at location 1023, sec. 25, T. 18 N., R. 16 E.

	Ft.	in.
Lignite, top not exposed		9
Shale, carbonaceous		8
Lignite		5
Shale, brown.		
Total section	1	10
Total lignite	1	2

Other sections measured in these townships are shown graphically on Plate XI.

[1] Todd, J. E., South Dakota Geol. Survey Bull. 4, p. 50, 1910

TPS. 20, 21, 22, AND 23 N., R. 16 E.

The area included in Tps. 20, 21, 22, and 23 N., R. 16 E., lies between the northern edge of the Big Meadow and the North Dakota State line and embraces a territory of more or less uniform topographic expression. The South Fork of Grand River, which flows from west to east across T. 21 N., occupies a comparatively narrow channel and receives the drainage from the entire area. To the south, the surface rises rather abruptly in rough badlands, so that an elevation of nearly 300 feet above the river level is reached in some places within a mile of the river bank. To the north, however, conditions are different. A terrace nearly 100 feet high rises very abruptly from the river, beyond which the surface is nearly level for a distance of more than a mile, and thence the altitude increases gradually until the maximum is reached at a distance of at least 10 miles from the river.

By far the greater portion of the area has been cultivated, and fairly good crops of small grains may be raised. Lemmon, the largest town in northwestern South Dakota (population 1,200), is on the north line of the State in secs. 20 and 21, T. 23 N., on the Chicago, Milwaukee & St. Paul Railway. Two important stage routes start from Lemmon, and as it is the only town on the railway in this region, it forms the shipping point for produce from nearly all of Perkins County as well as a considerable area in North Dakota. Excellent roads follow nearly every section line and connect all parts of the area.

Along the valley of Grand River the soft somber-colored shales of the lower part of the Lance formation are exposed at a number of places where recent erosion has dissected the surface. Within a short distance of the river the semibarren surface formed by these rocks is replaced by the grass-covered area in which the deep mantle of soil is the result of the disintegration of the sandy shale and soft sandstone of the overlying Ludlow lignitic member of the Lance. In the higher land north of the river the Cannonball marine member of the Lance and the Fort Union formation are the surface rocks, but the line between them is very obscure and its location is based mainly on topography.

Local lenses of lignite are exposed at two places near the top of the lower part of the Lance. At location 1028, in sec. 34, T. 21 N., R. 16 E., a bed 1 foot 6 inches thick is exposed near the main freight road between Lemmon and the country to the south. At location 1029 (see Pl. XI), in sec. 17 of the same township, a bed 1 foot 1 inch thick is exposed along the side of a small valley. At this point the overburden has been stripped in a small area and a few wagon loads of lignite have been removed for use among the farmers of the vicinity.

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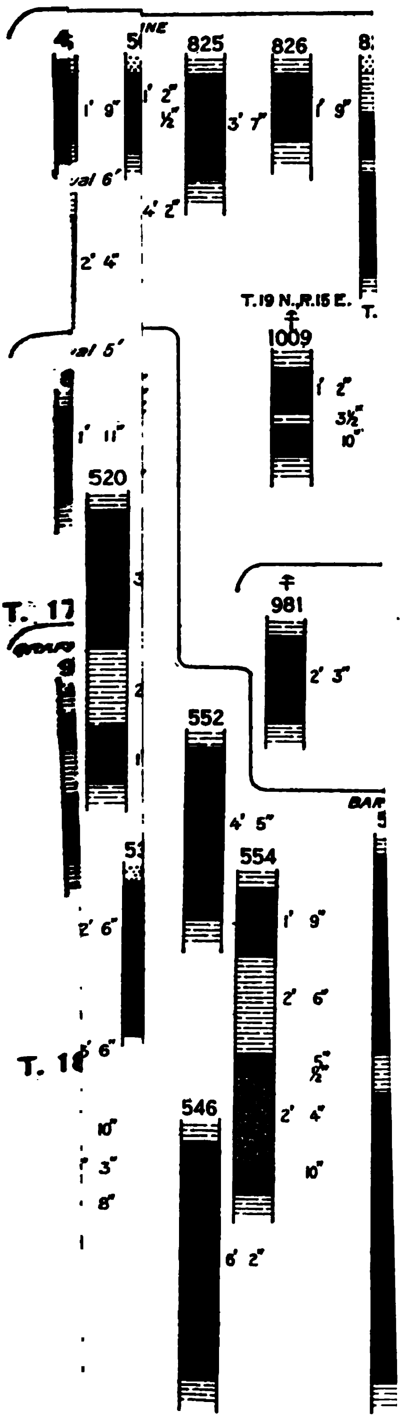

825
826
1' 9"
1' 2"
½"
3' 7"
1' 9"
4' 2"
2' 4"
T. 19 N., R. 15 E.
1009
1' 2"
3½"
10"
1' 11"
520
981
2' 3"
552
4' 5"
554
1' 9"
2' 6"
2' 6"
546
2' 4"
10"
3"
8"
10"
6' 2"

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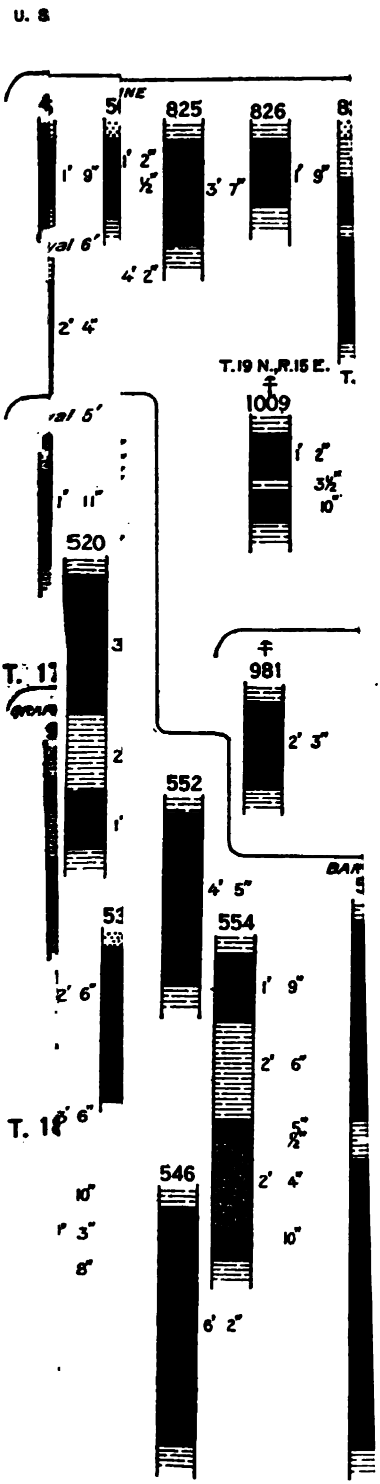
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4' 5"
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1' 9"
2' 6"
2' 6"
2' 4"
10"
546
6' 2"
10"
1' 3"
8"

At location 1027, in sec. 19, T. 20 N., the horizon at the top of the lower part of the Lance, at which, in many places, there are valuable lignite beds, is represented by 9 inches of lignite.

T. 17 N., R. 17 E.

The gently undulating, semibarren surface of T. 17 N., R. 17 E., is broken near the center by a series of low, flat-topped hills which rise more than 100 feet above the average altitude of this part of the field. Numerous farmers have settled in this township, in spite of the fact that soil derived from the clay shale does not make especially good farm land.

The Ludlow lignitic member of the Lance formation is exposed in the rather prominent hills near the center of the township, but the surface rock in the rest of the area belongs to the lower part of the Lance formation. A single lignite bed near the base of the Ludlow member is exposed at several places. A small drift mine at location 1032 (see Pl. XI), in sec. 16, known locally as the School Section mine, has been operated by the ranchers and farmers. Two drifts, each about 75 feet long, have been driven along the bed, but as the lignite has been mined by each ranchman for his own use no systematic development has taken place. A small strip mine was opened during the summer of 1911, at location 1031, in sec. 20, but at the time of examination only a small amount of lignite had been removed. Sections of the lignite beds exposed in this township are shown on Plate XI (locations 1030 to 1032).

TPS. 18, 19, 20, 21, 22, AND 23 N., R. 17 E.

In the area comprising the fractional townships along the eastern edge of the field the land south of South Fork of Grand River is semibarren, locally dissected into badlands by recent erosion, and therefore of little value for farming. However, a large number of settlers have taken up land in the area and their efforts to raise crops of small grains, potatoes, etc., are in some places being rewarded by success. North of the river the surface rises gradually in a more or less grass-covered country, traversed from north to south by two main open valleys. The soil in the lowlands area is derived from the clay shale of the Lance formation, but on the hills and slopes the overlying Ludlow lignitic and Cannonball marine members of the Lance and the Fort Union formation furnish the soil constituents and as a result the soil is sandy and more productive. In the upland area the mantle of soil is thick and there are practically no rock exposures from which to judge the bedrock conditions.

Lignite is exposed at only one place in the area (location 1033, in sec. 3, T. 21 N., R. 17 E.), and in October, 1911, the farmers of the

vicinity were mining lignite there for their own use. The bed, which has the following section, is near the top of the lower part of the Lance formation:

Section of lignite bed at location 1033, in sec. 3, T. 21 N., R. 17 E.

	Ft.	in.
Shale, sandy.		
Lignite		9
Shale, drab		3
Lignite	1	4
Shale, brown.		
Total section	2	4
Total lignite	2	1

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FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

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Bulletin 628

EOLOGY AND COAL RESOURCES OF

CASTLE VALLEY

IN CARBON, EMERY, AND SEVIER COUNTIES, UTAH

BY

CHARLES T. LUPTON

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GEOLOGY AND COAL RESOURCES OF CASTLE VALLEY IN CARBON, EMERY, AND SEVIER COUNTIES, UTAH.

By CHARLES T. LUPTON.

INTRODUCTION.

GENERAL STATEMENT.

Castle Valley includes parts of Carbon, Emery, and Sevier counties and is situated between the Wasatch Plateau and the San Rafael Swell, in the east-central part of Utah. (See Pl. XII and index map, fig. 1.) The outcrops of the coal-bearing rocks and adjacent formations of the Book Cliffs were mapped and studied by Richardson[1] from Grand River, Colo., westward and northwestward to the north end of Castle Valley. The writer traced from north to south the lowest formations studied by Richardson, beginning near Mounds (Sunnyside Junction), on the Denver & Rio Grande Railroad, and ending about 80 miles to the southwest in T. 26 S., R. 4 E., at the north end of Thousand Lake Mountain.

The rocks designated in this report the Ferron sandstone member of the Mancos shale contain the more important coal beds at the south end of Castle Valley east and south of Emery, but in the northern part of the area they contain no coal. Near Mounds these rocks consist of approximately 75 feet of soft yellowish sandstone characterized by a concretion-bearing stratum. Plate I, *A*, shows the character of the topography where these rocks crop out near Mounds. This sandstone increases in thickness toward the southwest, from about 75 feet at Mounds to about 800 feet at Last Chance Creek. (See columnar sections in Pl. IV, p. 32.) The character of the surface in this locality is shown in Plate I, *B*. In the southern part of the field 14 coal beds are exposed in these rocks. This coal has been described briefly by Taff,[2] who examined a few prospects and mines south of Emery in 1905 during his investigation of the higher (Mesaverde) coal-bearing rocks along the east scarp of the Wasatch Plateau.

[1] Richardson, G. B., Reconnaissance of the Book Cliffs coal field between Grand River, Colo., and Sunnyside, Utah: U. S. Geol. Survey Bull. 371, 1909.

[2] Taff, J. A., Book Cliffs coal field, Utah, west of Green River: U. S. Geol. Survey Bull. 285, p. 301, 1906.

OBJECT OF INVESTIGATION.

The primary object of this examination was to determine the quality and quantity of the coal in order that the land, part of which had been withdrawn from all forms of entry, might be classified, valued, and restored to entry. The method of determining the

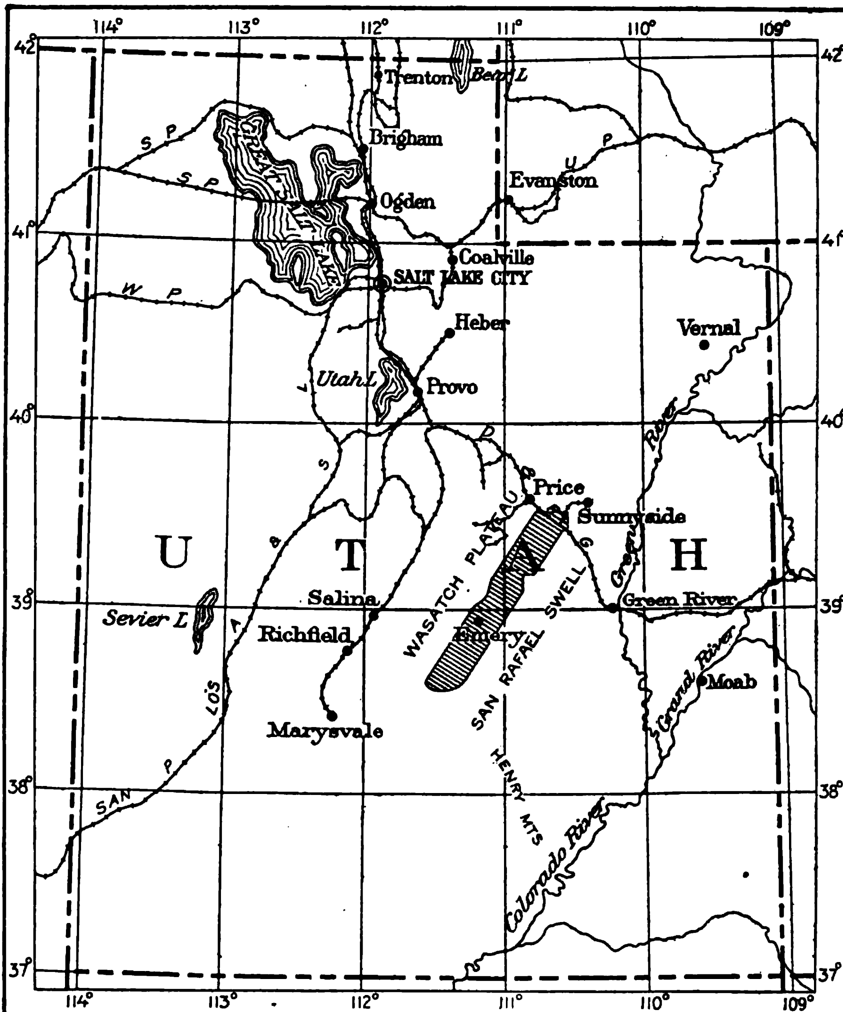


FIGURE 1.—Index map of Utah showing location of Castle Valley and the Emery coal field.

quality and quantity of the coal is discussed fully under "Method of field work" (pp. 10–11). A secondary purpose of the investigation was to collect geologic information regarding this region, of which little was definitely known. The age, character, and thickness of the coal-bearing formations, and their relations to the underlying and

A. COAL-BEARING ROCKS (FERRON SANDSTONE MEMBER OF THE MANCOS SHALE) NEAR MOUNDS, AT THE NORTHEAST END OF CASTLE VALLEY.

1, Book Cliffs, near Sunnyside.

B. COAL-BEARING ROCKS (IN FOREGROUND) NEAR LAST CHANCE CREEK, IN THE SOUTHWESTERN PART OF THE EMERY COAL FIELD.

1, Thousand Lake Mountain.

overlying rocks were studied. Fossils materially aid in determining geologic age, and a careful search along the outcrop was made for them. Data regarding the character and thickness of a formation are collected by carefully measuring and describing the various strata that compose it. The relations of contiguous formations are determined by an examination of the contact line separating them. The criteria that are usually relied upon as proof of a time interval between the periods of deposition of adjacent formations are (1) a discordance in the dip of the strata, (2) erosion channels, and (3) conglomerate. On the other hand, if the strata accord in dip and there are no signs of an erosional stage, fossils collected immediately above and below a contact line are often of importance in determining whether or not the beds are conformable.

HISTORY.

From 50 to 60 miles of the old Spanish Trail, which extended from Santa Fe, N. Mex., to Monterey, Cal., at the time these places were centers of Spanish civilization on this continent, lies in Castle Valley. The coal in this field may or may not have been known at the time this trail was used extensively.

Capt. J. W. Gunnison, of the Corps of Topographic Engineers,[1] traversed Castle Valley from north to south in the early part of October, 1853, on the way to Sevier Valley, where he and several of his party were killed by Indians a few days after passing through this field. Lieut. E. G. Beckwith, who wrote the report of this expedition, states, in his journal for October 11, 1853: "Specimens of coal were brought in from the hills near the camp, Capt. Gunnison and Dr. Schiel differing in opinion as to its quality." The party was camped at this date near the north end of the Emery coal field, about 3 miles east of Emery, approximately in sec. 12, T. 22 S., R. 6 E. So far as known this is the first published reference to the coal in this field.

During the summer of 1873 Lieut. R. L. Hoxie,[2] Corps of Engineers, and his party mapped the topography and geology of east-central and south-central Utah. Their route of travel led southward through Castle Valley and across this coal-bearing area. E. E. Howell,[3] who was with this party as geologist, referred to the coal in Castle Valley and along Muddy Creek. Robert Forrester[4] described briefly the coal on Quitchuppah and Ivie creeks and gave proximate analyses of both the "top vein" (bed I?) and the "bot-

[1] U. S. Pacific R. R. Expl., vol. 2, pp. 62–66, 1855.

[2] Wheeler, G. M., U. S. Geog. Surveys W. 100th Mer. Ann. Rept. for 1874, p. 5, 1874.

[3] Wheeler, G. M., U. S. Geog. Surveys W. 100th Mer. Final Rept., vol. 3, pp. 277, 279, 1875.

[4] U. S. Geol. Survey Mineral Resources, 1892, pp. 518–519, 1893.

tom vein" (bed C?). He considered these coals to be in a down-faulted portion of the Montana group, which is represented in part by the Mesaverde formation in the Wasatch Plateau, a few miles to the west. This classification has been the topic of considerable debate by those familiar with the coals of this part of Utah. J. A. Taff[1] in 1905 examined the coal-bearing rocks along the east face of the Wasatch Plateau and also noted the coal at the south end of Castle Valley described in the present report.

METHOD OF FIELD WORK.

This report is based on a detailed examination of the coal beds, of the geologic formations in which the coal occurs, and of some of the overlying and underlying formations. Field work was begun near Mounds, on the Denver & Rio Grande Railroad, July 17, 1911, and was terminated at Ivie Creek on October 7 of the same year. That part of the coal field lying south of Ivie Creek was examined from September 9 to November 3, 1912. Detailed work on the coal beds in the vicinity of and 30 miles south of Emery (see Pl. X, p. 74) was done from September 8 to October 7, 1911, and from September 9 to November 3, 1912.

A system of triangulation was developed over the area as an aid in mapping surface features other than coal, such as roads, trails, houses, streams, and rock ledges. North of Ivie Creek this primary control was established by means of a 24-inch Johnson plane table and a Gale telescopic alidade on a scale of 1 inch to 1 mile.

The outcrop of each coal bed was mapped with relation to land corners and the thickness of the coal beds was measured at as many places as seemed necessary in order to obtain accurate information regarding the variations in character and thickness. Many Government corner monuments near the coal outcrops were located, and enough others were found some distance from the coal outcrops to enable the accurate mapping of the Emery coal field. The coal beds from the vicinity of Emery at the north edge of the field southward to Willow Creek, except in a small area north of Ivie Creek and west of Quitchuppah Creek, were mapped by means of a 15-inch Bumstead plane table and a Gale alidade on a scale of 2 inches to 1 mile. (See Pl. X.) Mines, prospects, and points at which the coal beds were measured were located by stadia. The coal beds and geologic boundaries between Ivie and Quitchuppah creeks were located by triangulation at the time the primary control was obtained. That part of the coal field lying south and southwest of Willow Creek was mapped by the triangulation method on a scale of 2 inches to 1 mile. Samples of coal for analysis (see p. 80) were collected at seven places and represent the three principal coal beds

[1] Op. cit., pp. 289–302.

(A, C, and I) in the field. (See table of analysis, p. 80.) The geologic unit in which the coals occur was examined, and sections of these rocks were measured at different places. Fossils were collected wherever possible and are listed under "Geology" (pp. 19–43). Formations overlying and underlying the coal-bearing rocks were studied, and sections of them were measured in detail in order to obtain a general conception of the geologic column in this vicinity. A geologic section, from the lowest rocks observed by the writer in the interior of the San Rafael Swell, lying to the east, to the highest rocks on top of the Wasatch Plateau, a few miles to the west, is given by formations under "Stratigraphy" (pp. 19–39).

LAND SURVEY.

Castle Valley, the greater part of which has been subdivided into sections, was surveyed with relation to the Salt Lake base and meridian. Nearly all of this work was done by A. D. Ferron, after whom the town of Ferron, in Emery County, was named. The coal-bearing portion of the area included within Tps. 21, 22, 23, 24, 25, and 26 S., Rs. 4, 5, 6, and 7 E., is described in greater detail than the remainder of the field, which lies to the north and northeast of Emery. The southeastern part of T. 21 S., R. 6 E.; T. 21 S., R. 7 E., except the southeastern part; T. 22 S., R. 6 E., except about four sections in the northwestern part; and the northwestern part of T. 23 S., R. 6 E., were surveyed by Mr. Ferron in July and August, 1873. In May, 1881, T. 23 S., R. 5 E., except the northwestern part, was subdivided by the same surveyor. The eastern part of T. 22 S., R. 5 E., and the north half of T. 24 S., R. 5 E., were subdivided by Mr. Ferron in August and October, respectively, 1890. Mr. Ferron and A. Jessen subdivided the east half of T. 26 S., R. 4 E., in November, 1892, and in June, 1895, they surveyed the east-central part of T. 25 S., R. 4 E. In July, 1896, A. P. Hanson made a survey of the south-central and west-central parts of T. 25 S., R. 5 E. The survey of the northeastern part of T. 23 S., R. 6 E., was completed in November, 1909, by Mr. Ferron. All this work was done under the contract system. The two remaining tracts of the Emery coal field (see Pl. X, p. 74), the southeastern part of T. 21 S., R. 7 E., and all of T. 22 S., R. 7 E., were subdivided in May, 1910, by H. W. Miller and A. Nelson, who were in the direct employ of the General Land Office. Under the contract system the section and quarter-section corners are marked by stone monuments, a large number of which are still in place and easily read. The corners in the areas surveyed in 1910 by the General Land Office are marked by iron pipes with copper caps on which the positions of the monuments are recorded.

The recent surveys in Tps. 21 and 22 S., R. 7 E., and T. 23 S., R. 6 E., and the results of the triangulation and stadia work of the geologic party in 1911 and 1912 seem to indicate that the lines of the

older surveys are in places slightly longer than those given on the township plats.

The land net at the south end of the coal-bearing area in Tps. 24 and 25 S., Rs. 4 and 5 E., as shown on the accompanying maps (Pls. X and XII), differs from that which is given on the General Land Office plats of these townships. A sufficient number of Government corners were located by the triangulation method used by the writer to prove definitely that the line connecting the corners between T. 25 S., R. 4 E., and T. 25 S., R. 5 E., and that part of T. 25 S., R. 5 E., which was surveyed with relation to that line, are about 850 feet west of the positions indicated on the Land Office plats, thus narrowing the width of the east tier of sections of T. 25 S., R. 4 E., by that amount. In the construction of the accompanying maps (Pls. X and XII) the northeast corner of T. 25 S., R. 4 E., and the corresponding corner of T. 24 S., R. 4 E., were connected by a straight line whose bearing is greater than that (S. 4° W.) indicated on the Land Office plat of T. 24 S., R. 5 E. The change in the bearing of this line necessarily makes the east-west dimensions of the west tier of sections in T. 24 S., R. 5 E., greater than those given on the township plat. The discrepancy above described is attributed by A. D. Ferron, who ran the line between Rs. 4 and 5 E. through Tps. 24 and 25 S., to the short chaining of the fifth standard parallel south.

ACKNOWLEDGMENTS.

The field work in 1911 was done with the assistance of B. W. Clark and A. E. Fath. W. L. Mielke and Millard Massey served as camp hands and rendered efficient aid in rodding and in uncovering and measuring coal beds. In 1912 the writer was assisted in the field by R. V. A. Mills, Millard Massey, Arthur Massey, Merrill Allred, and Casper Christensen. In the office the careful work of R. V. A. Mills, Frank R. Clark, and E. R. Lloyd has made the report much more complete. The writer desires especially to acknowledge the favors granted by the officials of the Emery County recorder's office at Castledale, and also the courtesy and hospitality of the settlers throughout the field. Ira R. Browning also gave information of value.

GEOGRAPHY.

POSITION AND EXTENT.

The area mapped in Castle Valley extends S. 30° W. from Mounds and lies between meridians 110° 30′ and 111° 20′ W. and parallels 38° 35′ and 39° 30′ N. The entire field is about 80 miles long, ranges from 10 to 20 miles in width, and includes about 1,000 square miles. The index map (fig. 1) shows the relative position of this area in the State. The geology of the entire valley is represented on Plate XII.

That part of Castle Valley known as the Emery coal field is shown in detail on Plate X.

The Emery coal field is at the south end of Castle Valley, between meridians 111° 3′ and 111° 20′ W. and parallels 38° 35′ and 39° N. The greater part of this area lies along the west side of Emery County south of the middle, the remainder being included in the southeastern part of Sevier County. This coal field is about 25 miles long from north to south, and 22 miles wide from east to west, and includes about 300 square miles of land underlain by coal.

SETTLEMENTS.

The principal settlements in that part of Castle Valley described in this report are, in order from north to south, Wellington, Farnham, Mounds, Victor, Desert Lake, Cleveland, Huntington, Lawrence, Castledale, Orangeville, Clawson, Ferron, Molen, Rochester, and Emery. Wellington, on the Denver & Rio Grande Railroad, in secs. 6 and 7, T. 15 S., R. 11 E., has a population of about 375 people. Farnham is a flag station on the railroad in sec. 22, T. 15 S., R. 11 E. Mounds, in the SE. ¼ SE. ¼ sec. 5, T. 16 S., R. 12 E., is at the junction of the Sunnyside branch and the main line of the Denver & Rio Grande Railroad. It has a population of about 50 persons and consists of a few houses and a railroad station. Victor, in the S. ½ sec. 29, T. 16 S., R. 11 E., and Desert Lake, in the N. ½ sec. 11, T. 17 S., R. 10 E., are small settlements, each containing less than 100 inhabitants. Victor has a store and both have post offices. The town of Cleveland is in T. 17 S., on both sides of the line separating Rs. 9 and 10 E., in secs. 13 and 18, respectively. The 200 or more inhabitants support two or three stores and a good school. Huntington, the oldest settlement in the valley, has a population of about 800 persons, and is on Huntington Creek in T. 17 S., on both sides of the line separating Rs. 8 and 9 E., in secs. 24 and 25 and secs. 19 and 30, respectively. This town is the center of a prosperous farming community and is well supplied with schools, churches, hotels, and stores. Lawrence has about 80 inhabitants and a dozen or more houses on Huntington Creek, mainly in secs. 32 and 33, T. 17 S., R. 9 E. Castledale, the county seat of Emery County, is on Cottonwood Creek, in secs. 33 and 34, T. 18 S., R. 8 E. The 700 or more inhabitants support schools, hotels, churches, and numerous stores. The town is lighted by electricity and has the only academy in the southeastern part of Utah. Orangeville (not shown on the map), with a population of about 650, is also on Cottonwood Creek, about 3½ miles northwest of Castledale, in the southwestern part of the same township. Clawson is a small hamlet in sec. 26, T. 19 S., R. 7 E. It supports a church, school, and small store. The settlers receive their mail by means of a "star"

mail route out of Castledale. Ferron, on Ferron Creek, mainly in secs. 9 and 10, T. 20 S., R. 7 E., has a population of about 650 persons. It is similar to Castledale, Huntington, Emery, and Cleveland in the number and character of stores, hotels, schools, and churches. Molen, also on Ferron Creek, in secs. 7 and 18, T. 20 S., R. 8 E., has about a dozen houses, a church, and a school, but neither store nor post office. The settlers in this locality receive their mail at Ferron. Rochester, in the southwestern part of T. 21 S., R. 7 E., is a small settlement without a post office. Emery, a village of about 550 inhabitants, mainly in secs. 4 and 9, E. 22 S., R. 6 E., is the principal town in the coal field at the south end of Castle Valley. The people living here are for the most part farmers who cultivate the irrigated lands adjacent to the village. A few ranchers live south and southwest of Emery on Quitchuppah Creek and along Muddy Creek in sec. 36, T. 22 S., R. 6 E. Emery and the several other towns mentioned above have daily mail connections with Price, the county seat of Carbon County, on the Denver & Rio Grande Railroad, 65 miles north of Emery.

The principal occupations of the settlers of Castle Valley are farming and stock raising. Some allied industries, however, such as fruit raising and the production of honey, are given considerable attention. At Mohrland, the southern terminus of the Castle Valley Railroad, in the northern part of T. 16 S., R. 8 E., outside of the area examined in 1911, considerable coal is mined from the upper coal-bearing formation (Mesaverde), to the study of which little attention was given in this examination. Some coal is mined by the ranchers for domestic use east and south of Emery in the lower coal-bearing rocks, which are fully described in this report.

ROADS AND TRAILS.

A very good stage road extends the entire length of Castle Valley from Price through Huntington, Castledale, and Ferron to Emery. Numerous other first-class and second-class roads and trails make the greater part of the area accessible. In general, every main stream is paralleled by one or more roads leading into the canyons cut into the Wasatch Plateau to the west, where wood and coal are abundant. A good road has been constructed from Wellington, on the Denver & Rio Grande Railroad, to Huntington through Cleveland. A branch of this road connects with the Price-Emery stage road about 4 miles south of Price. A second-class road from Castledale follows closely the route of the old Spanish Trail across the north end of the San Rafael Swell to Green River, the easternmost town in Emery County, on Green River, in T. 21 S., R. 16 E. Green River Desert, which lies about 40 to 70 miles southeast of Castle Valley, is accessible by means of a poor and rarely used road from Ferron through Molen and to

the southeast. A road from Castledale through Buckhorn Flat and along Buckhorn Wash also leads through "Sinbad" to the desert. From Emery two roads to the east have been constructed. One about 20 miles in length leads through Rochester and Dry Wash to the Globe copper mine. The other extends to the southeast about 18 miles to a supposed oil field on Salt Wash, 2 miles above its junction with Muddy Creek. A wagon trail, very rarely used, connects Emery with Caineville, on Fremont River, 60 miles to the southeast. A fairly good road connects Emery with Fremont and Loa, to the south, near the head of Fremont River. Emery is also connected with Salina, west of the Wasatch Plateau, by a fair mountain road that follows the courses of Ivie, Yogo, and Salina creeks.

DRAINAGE AND WATER RESOURCES.

Castle Valley is drained entirely by Price, San Rafael, and Curtis rivers and their tributaries, each river receiving about one-third of the run-off. The following table gives the average flow, during the months when irrigation is necessary, of some of the streams in Castle Valley that have been measured by the United States Geological Survey, in 1909[1] and 1913.[2]

Partial amount of run-off across Castle Valley during May, June, July, and August, 1909 and 1913.

Stream.	May.	June.	July.	August.
1909.	*Second-feet.*[a]	*Second-feet.*	*Second-feet.*	*Second-feet.*
Price River	[b] 1,030	925	167	146
Huntington Creek	467	741	191	107
Cottonwood Creek	416	842	218	438
Ferron Creek	146	372	27.6	207
Muddy Creek	146	245	109	(?)
1913.				
Price River	480	238	193	65.0
Huntington Creek	376	218	126	70.9
Cottonwood Creek	711	401	111	50.5
Ferron Creek	257	208	75.2	27.4
Muddy Creek	169	132	80.6	51.0

[a] Second-feet is the number of cubic feet of water passing a given point in a stream channel each second
[b] Mean daily run-off.

This table indicates that the run-off is greatest in most streams during June and that in July and August they carry much smaller volumes. The irregularities in the run-off for the different streams during any month are probably due to local rainstorms. The water from the streams in Castle Valley is utilized mainly for irri-

[1] Freeman, W. B., and Bolster, R. H., Surface water supply of the United States, 1909, Part IX, Colorado River Basin: U. S. Geol. Survey Water-Supply Paper 269, pp. 77–79, 81–87, 181–183, 233, 234, 1911.

[2] Follansbee, Robert, Porter, E. A., and Gray, G. A., Surface water supply of the United States, 1913, Part IX, Colorado River basin: U. S. Geol. Survey Water-Supply Paper 359, pp. 70–76, 79–84, 175–177, 1916.

gating the adjacent valley bottoms. In the vicinity of Cleveland, however, which lies in the drainage basin of Price River, irrigation is made possible by water brought from Huntington Creek over a low divide through a canal 15 miles in length. Near Emery a similar condition exists. The water is taken from Muddy Creek near the mouth of the canyon cutting the Wasatch Plateau and is carried by a large canal through a divide by means of a tunnel to the flat country about Emery.

Practically all the water in the streams flowing east from the Wasatch Plateau across the area under consideration is now used for irrigation with the exception of that in Last Chance Creek. Part of the water from this creek is diverted from its natural course and carried by ditches to Paradise Lake, in secs. 14 and 23, T. 25 S., R. 4 E.

The irrigated area of Castle Valley may possibly be increased as much as 100 per cent by the construction of storage reservoirs to hold flood waters and the spring run-off in the deep canyons in the Wasatch Plateau.

The writer knows of few springs of any importance in Castle Valley north of Ivie Creek. One of these, on the outcrop of the Ferron sandstone member of the Mancos shale in the SW. ¼ sec. 24, T. 21 S., R. 7 E., furnishes sufficient excellent water for a few head of stock the year round. Farther north in Castle Valley there are a few small seeps of alkali water issuing from the shale above the Ferron sandstone. They are locally known as "poison springs," owing to the very alkaline character of the water. South of Ivie Creek, in the more rugged part of the valley, springs are more numerous and the character of the water is much better. Willow Spring, near the center of sec. 13, T. 24 S., R. 5 E., is the best in the southern part of the coal field. In the vicinity of Paradise Lake springs are plentiful. At the extreme southwest end of the field, in the W. ½ sec. 34, T. 25 S., R. 4 E., there is another spring of excellent water.

Paradise Lake, in the S. ½ sec. 14 and N. ½ sec. 23, T. 25 S., R. 4 E., receives part of its water from small mountain streams heading west and southwest of the lake, but, as stated above, it is partly supplied with water diverted from Last Chance Creek. The lake covers about 160 acres and has no outlet. However, should the water rise more than 32 feet from its level in October, 1912, it would flow through an old water gap into a canyon to the southeast. This lake is included within the limits of the Hogan ranch, and is used by the owners of this property to furnish water for their cattle.

In places in the area mapped (Pl. XII, p. 86) fairly good water could be obtained probably by drilling into the Dakota sandstone and also into some of the conglomeratic sandstone beds in the under-

lying McElmo formation, as has been done in the vicinity of the town of Green River, Utah.[1]

Water may be found in places in the southwestern part of the field in stream channels where depressions have been eroded into the soft massive sandstone of the Ferron member. In one locality, sec. 34, T. 24 S., R. 5 E., a pothole at least 10 feet deep and 3 or 4 feet in diameter was half full of water in October, 1912. Other natural reservoirs of the same type but of smaller dimensions exist in this general locality.

CLIMATE AND VEGETATION.

The climate of Castle Valley is semiarid, as shown by the annual rainfall,[2] which ranges from about 7½ inches at Emery to 8½ inches at Castledale. The yearly rainfall at Price is greater than either of the above measurements indicates and probably is about 11 inches. This figure was obtained by averaging the precipitation at Sunnyside, where the annual rainfall is 14.86 inches, and at Castledale. The temperature in Castle Valley ranges from 104° to —34° F. and averages about 45.7° F.

Vegetation, consisting mainly of a sparse growth of grass, a little sagebrush, greasewood, and cactus, is scanty away from stream courses where irrigation is not carried on. Piñon is common on the sandstone ridges and scarps north of Ivie Creek. South of this creek native vegetation is much more abundant. Along many of the streams willow and cottonwood trees are plentiful and other vegetation is more luxuriant than away from the streams. Irrigated lands produce grain, vegetables, alfalfa, and many kinds of fruit. In Castle Valley practically all kinds of fruits common to temperate climates with the exception of grapes are raised.

SURFACE FEATURES.

GENERAL STATEMENT.

Castle Valley is bounded on the west by the Wasatch Plateau and on the east by the San Rafael Swell. To give an adequate idea of the surface of the valley it is necessary to describe, briefly at least, the adjacent topographic features. Topographic maps of this region with a contour interval of 250 feet were made by the Powell Survey. (See San Rafael topographic map of the United States Geological Survey.)

[1] Lupton, C. T., Oil and gas near Green River, Grand County, Utah: U. S. Geol. Survey Bull. 541, pp. 117–121, 1914.

[2] Summary of the climatological data for the United States, section 10, Eastern Utah, pp. 2–4, U. S. Weather Bureau.

WASATCH PLATEAU.

The Wasatch Plateau, lying west of Castle Valley, is a southward continuation of the kinds of rocks and type of topography embodied in the Book Cliffs, which form the prominent scarp extending along the north side of the Denver & Rio Grande Railroad from Grand River, Colo., to Castle Gate, Utah. The Wasatch Plateau ranges from 2,000 to 3,000 feet in height above the floor of Castle Valley, and at many points it is impossible to scale its east face. At only a few places can it be traversed with a wagon or buggy. Deep canyons have been cut into the plateau by Huntington, Cottonwood, Ferron, Muddy, Quitchuppah, Ivie, and Last Chance creeks and some of their tributaries. Low on the east scarp of the plateau alluvium has been washed down into symmetrical fanlike forms, which in many places merge with one another, thus forming compound alluvial fans. Remnants of alluvial fans of former stages of erosion are numerous higher on the east flank of the plateau. These remnants have been rather fully dissected by minor intermittent streams.

The Book Cliffs consist of almost flat-lying beds of sandstone and shale and rise 3,000 to 4,000 feet above the adjacent country. Wherever erosion has removed the overlying sandstone the shale, being less resistant than the sandstone, has yielded readily to erosion, producing nearly sheer cliffs instead of gentle slopes.

CASTLE VALLEY.

Castle Valley is literally a monoclinal valley and owes its existence to the presence of a soft, relatively homogeneous shale which is easily eroded wherever the overlying sandstone is removed. The valley is 80 miles or more in length, and all of it is included within the area mapped except that part in Carbon County north of the Denver & Rio Grande Railroad. The topography of Castle Valley north of Ivie Creek is characterized mainly by gentle slopes, which develop into bad lands near the Wasatch Plateau and in the vicinity of stream courses. South of Ivie Creek the topography is more rugged, owing to the extensive mantle of gravel and bowlders derived from the basalt-covered area to the southwest. The gravel and bowlders have very noticeably protected the underlying shale from erosion, and the resulting topographic forms are entirely different from the forms north of Ivie Creek. Along the east side of Castle Valley parallel cliffs similar to the east face of the Wasatch Plateau above described are developed by the erosion of strata of unequal resistance. In passing from the Wasatch Plateau across Castle Valley into the San Rafael Swell one descends stratigraphically several thousand feet. A view westward from the interior of the Swell gives the impression of looking up a very gently inclined varicolored stairway, the steps of which increase in height toward the top, represented by the Wasatch Plateau.

Castle Valley ranges in altitude from 5,300 feet on Price River, at the north end of the valley, to 8,550 feet in the vicinity of the Hogan ranch, near its south end.

The boundary separating the San Rafael Swell from Castle Valley, arbitrarily adopted by the writer, roughly follows the western limit of the irregular rows of buttes, mesas, and "castles" that form the western boundary of "Sinbad." The buttes and "castles" here referred to are conspicuously shown on the United States Geological Survey's San Rafael topographic sheet.

SAN RAFAEL SWELL.

The most prominent feature of the topography of the San Rafael Swell is a series of odd-shaped sandstone forms which encircle an area in the heart of the Swell, locally known as "Sinbad," which is 40 to 50 miles long and 10 to 20 miles wide. These fantastically eroded forms are remnants of the outcrop of a massive cross-bedded gray Jurassic sandstone about 800 feet thick. It is practicable to cross the Swell at only a few places on account of the almost impassable barrier formed by this sandstone rim. Nearly vertical scarps and canyon walls 300 to 500 feet in height are common. Low hogbacks formed by resistant beds in the strata overlying this sandstone, the upper surfaces of which produce dip slopes of varying extent, depending on the inclination of the beds, encircle this belt of rugged topography. Badlands are common, especially near stream courses.

GEOLOGY.

STRATIGRAPHY.

GENERAL FEATURES.

During the investigation in Castle Valley reconnaissance excursions were made to the Wasatch Plateau and the interior of the San Rafael Swell,[1] enabling the writer to discuss in a general way the stratigraphy from the lowest rocks (Triassic and Permian) studied in the Swell to the highest (Green River?) capping the Wasatch Plateau. Throughout the greater part of Castle Valley the upper part of the McElmo formation, the Dakota sandstone, and the greater part of the Mancos shale were carefully mapped. All other formations described were examined, some in detail, as shown by the compiled stratigraphic section, and others in a general way, as indicated in the descriptions below. Numerous fossil collections were made, and the reports of the determinations of these collections are presented in the descriptions of the several formations.

[1] Lupton, C. T., Notes on the geology of the San Rafael Swell, Utah: Washington Acad. Sci. Jour., vol. 2, No. 7, pp. 185–188, 1912.

The following summarized description of the Triassic and younger strata is given in tabular form for convenient reference and direct comparison:

Rock formations outcropping across Castle Valley from the interior of San Rafael Swell to the top of Wasatch Plateau, Utah.

System and series.	Formation.	Description of strata.	Thickness.	Economic value.
Quaternary (Recent).		An extensive mantle of soil, low gravel-capped terraces, and low broad compound alluvial fans.	0-50+ feet.	
Quaternary? (Pleistocene?)		Remnants of alluvial fans high up on the east face of Wasatch Plateau and lower table-lands. High terrace gravel with pebbles up to 1 foot in diameter. Gravel of both divisions of the Pleistocene (?) consists of yellowish-gray sandstone, gray and drab limestone, quartzitic sandstone, and black chert north of Ivie Creek and principally of dark basalt south of that creek.	0-50 feet. 0-40 feet.	Small springs issue from these beds.
Tertiary (Eocene).	Unconformity. Green River (?) formation.	Mainly grayish-drab fine-grained calcareous sandstone and sandy shale, which weather white and outcrop in cliffs.	Not determined, probably about 800 feet.	Oil shale reported.
	Wasatch formation. Unconformity.	Beds not well exposed but wherever observed, mainly sandstone, and sandy shale of various colors, red, yellow, and drab predominating. The outcrop of this formation forms smooth topography.	Not determined, probably about 1,000 feet.	Water bearing and is known to carry thin beds of coal near Colton and Wales, Utah.
Cretaceous (Upper Cretaceous).	Mesaverde formation.	Mainly beds of massive and medium-bedded sandstone with some sandy shale, all of a yellowish-gray color. Several coal beds are known to be present near the middle of the formation. None are known in the lower part of the formation up to a horizon 200 or 300 feet above the base. The lower part contains more shale than the upper.	About 1,200 feet, possibly more.	Commonly includes several thick beds of good bituminous coal.
	Mancos shale.	Yellow to bluish-drab sandy shale. Upper part very sandy, containing beds and lenses of sandstone. Middle and lower parts but slightly sandy.	About 3,000 feet.	
		Ferron sandstone member. Alternating beds of sandstone and sandy shale with several coal beds present in the vicinity of Emery. At Mounds this member is represented by about 75 feet of sandy material which generally contains a concretionary zone near the middle.	Varies from 75 feet near Mounds to about 800 feet on Last Chance Creek.	Several beds of good bituminous coal at the south end of Castle Valley.
		Bluish-drab sandy shale. Sandy material most plentiful near base and top of this part of formation.	About 600 feet.	
	Dakota sandstone. Probable unconformity.	Yellowish-gray sandstone with thin beds of shale, alternating. Sandstone coarse, soft, and in places very conglomeratic. Near the north end of Castle Valley the formation is mainly conglomerate. The lower part grades into sandy shale.	60 to 100 feet and possibly more.	A little coal of no importance in Castle Valley.

Rock formations outcropping across Castle Valley, etc.—Continued.

System and series.	Formation.	Description of strata.	Thickness.	Economic value.
Jurassic (?).	McElmo formation.	Variegated sandstone and sandy shale. The upper 500 feet principally gray and containing some conglomerate whose pebbles are in places 3 inches in diameter. About 800 feet above the base is a gray to white sandstone about 200 feet thick which probably corresponds to the Salt Wash sandstone member.[a] The lower 800 feet of beds are mainly red in color. About 200 feet above the base is a prominent gypsum horizon in which 40 feet of very pure gypsum is exposed. Another gypsum bed 10+ feet thick is exposed about 700 feet below the top of the formation.	About 1,850 feet.	Two or three gypsum beds of importance. Manganese southeast of Castledale.
Jurassic.	La Plata sandstone.	Highly cross-bedded coarse gray sandstone, weathering into odd-shaped buttes, mesas, and "castles." A shaly bed near the middle of the formation is present in places.	Not measured, estimated at 800 feet.	A little copper and some asphaltum-saturated sandstone; also locally water bearing.
	Probable unconformity.			
Triassic.	Vermilion Cliff sandstone.	Mainly varicolored sandstone and sandy shale. In places conglomeratic near the top. About 200 feet below the top asphaltum seeps were noted at a few places.	Full thickness not determined; about 500 feet was examined.	Asphaltum. Some thin lenses of relatively pure alum (sodium variety).
Carboniferous (Permian) and Triassic.		Gray medium-bedded sandstone exposed in the drainage basin of Mexican Spring Wash in "Sinbad."	800± feet exposed (according to Forrester's unpublished notes).	Sulphur springs and deposits on San Rafael River at east side of Swell.

[a] Lupton, C. T., Oil and gas near Green River, Grand County, Utah: U. S. Geol. Survey Bul. 541, p. 127, 1914.

CARBONIFEROUS (PERMIAN) AND TRIASSIC ROCKS.

It is believed that rocks of Permian and Triassic age older than the Vermilion Cliff sandstone are exposed on one of the southern tributaries of San Rafael River, near the west side of "Sinbad," 1 mile or more west of a prominent butte locally known as The Wickiup and about 1 mile east of Mexican Spring Wash. The sulphur deposit on San Rafael River, approximately in the north-central part of T. 21 S., R. 13 E., described by Hess[1] and visited by the writer, is situated stratigraphically a few hundred feet below the top of these rocks.

Robert Forrester in unpublished notes reports about 800 feet of Carboniferous beds exposed along San Rafael River near the Black Box, below Lockhart's cabin. These beds are lower than any examined by the writer. Fossils found by Forrester at this locality and identified by G. H. Girty are listed below.

[1] Hess, F. L., A sulphur deposit in the San Rafael Canyon, Utah: U. S. Geol. Survey Bull. 530, pp. 347–349, 1913.

The first eight in the list came from a stratum 30 feet below the one in which the remainder were found. Mr. Girty states that these fossils are characteristic of the "Bellerophon limestone" or top of the Aubrey group.

Allorisma capax.
Sedgwickia sp.
Myalina aff. M. congeneris.
Schizodus? sp.
Aviculipecten coloradoensis?
Pleurotomaria? sp.
Macrocheilina? sp.
Orthoceras? sp.
Sponge.
Lioclema? sp.
Composita mexicana?
Solenomya? sp.
Edmondia gibbosa?
Sanguinolites?? sp. a.
Sanguinolites?? sp. b.
Leda obesa.
Nucula levatiformis.
Mytilus? sp.
Pleurophorus? sp.
Astarte? sp.
Plagioglypta canna.
Dentalium mexicanum.
Euphemus subpapillosus.
Patellostium aff. P. nodicostatum.
Bellerophon sp. 1.
Bellerophon sp. 2.
Warthia? sp.
Coloceras n. sp.
Gastrioceras sp.
Ammonoid??

TRIASSIC SYSTEM.

VERMILION CLIFF SANDSTONE.

The base of the Vermilion Cliff sandstone was not determined, and the section given below represents careful estimates rather than accurate measurements of the thickness of the strata. The formation is prevailingly sandy and red. The lower part consists of thin to medium bedded sandstone and sandy shale which is yellowish gray below but changes to red in its upper part. Overlying this series is a grayish-brown coarse-grained sandstone about 90 feet thick, which in places is conglomeratic. At several localities asphaltum seeps and springs exist near the base of this bed. About 100 feet of varicolored sandy and conglomeratic material overlies this sandstone. The presence of a conglomerate near the top of this formation suggests an unconformity, but the evidence on this point is not conclusive, as no fossils were collected in the Vermilion Cliff or the overlying La Plata sandstone.

Section of part of Vermilion Cliff sandstone near west side of "Sinbad," in the San Rafael Swell.

[Thickness estimated.]

Top.	Feet.
Sandstone, red, maroon, purple, and gray, with beds of thin conglomerate and sandy shale of similar colors	100
Sandstone, grayish brown, in places conglomeratic (horizon of asphaltum seeps and springs near base of this sandstone)	90
Sandstone and sandy shale, red in upper part, yellow and gray in lower part, thin to medium bedded	300
	490

JURASSIC SYSTEM.

LA PLATA SANDSTONE.

The La Plata sandstone consists of a highly cross-bedded coarse-grained, very massive gray sandstone, but near the middle of the formation there is in places some shale, which, however, is not persistent. Careful estimates place the total thickness of this sandstone at about 800 feet along the west flank of the San Rafael Swell, where its outcrop has been eroded into prominent scarps, "castles," buttes, and mesas, from which Castle Valley probably takes its name. This sandstone is in all probability the same as the White Cliff sandstone of the eastern Uinta and southern Utah sections of Powell,[1] and corresponds to the La Plata sandstone of Cross.[2] This correlation is based solely on its stratigraphic position and physical characteristics, as no fossils were collected from it.

JURASSIC (?) SYSTEM.

McELMO FORMATION.

The McElmo formation, which is thicker in this locality than at any of the places in eastern Utah and southwestern Colorado, where it has been measured, consists of 1,800 to 1,900 feet of varicolored conglomeratic sandstone and sandy shale, with two or more gypsum beds[3] that form but a small part of the whole thickness. The lower 800 feet is composed mainly of sandstone and sandy shale, with gypsum-bearing beds about 200 feet above the base. The upper 400 feet of this part of the formation is mainly red and massive. Overlying this is a gray to white sandy series about 200 feet thick containing a thin stratum of conglomerate at the base. This portion is believed to be equivalent to the Salt Wash sandstone member[4] in the vicinity of Green River, Utah. Variegated sandstone and sandy shale, interbedded, and about 36 feet of gypsum, included in three benches, make up the overlying 350 feet of strata. The top of this 350-foot series probably coincides with the top of the Flaming Gorge formation as defined by Powell.[5] Gale,[6] however, in northwestern Colorado and northeastern Utah draws the contact between the Flaming Gorge formation and the Dakota

[1] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto, pp. 52, 53, 152, U. S. Geol. and Geog. Survey Terr., 1876.

[2] Cross, Whitman, and Purington, C. W., U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), p. 3, 1899.

[3] Lupton, C. T., Gypsum along the west flank of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 530, pp. 221–231, 1913.

[4] Lupton, C. T., Oil and gas near Green River, Grand County, Utah: U. S. Geol. Survey Bull. 541, pp. 124, 126, 127, 1914.

[5] Powell, J. W., op. cit., pp. 152, 157.

[6] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, p. 54, 1910.

sandstone about 500 feet stratigraphically higher, a determination that includes within the Flaming Gorge about 500 feet more of strata than Powell included in it. This 500 feet consists of sandstone, sandy shale, and conglomerate of a greenish-drab color and apparently corresponds to part of the Henrys Fork group as defined by Powell and as identified by Gilbert[1] in the Henry Mountains. In places the colors change to red, maroon, and blue. Considerable conglomerate occurs near the base. In Castle Valley the conditions apparently are similar to those described by Gale, and the positions of the geologic boundaries are similarly located. The McElmo formation as recognized in this field is believed to include not only the McElmo formation described by Cross[2] as occurring in southwestern Colorado, where it is considered the equivalent of the Morrison formation, but also a series of marine beds that probably represent a part at least of the Sundance formation. Fossils collected near the south side of sec. 10, T. 21 S., R. 9 E., on the east side of Coal Wash, about a mile slightly east of south from Dripping Spring, within 10 feet of the base of the formation were identified by T. W. Stanton as belonging to a marine Jurassic fauna. Plate II, *A*, shows the strata in which the fossils were collected and also the contact of the McElmo formation and the La Plata sandstone. The names of the species are as follows:

Ostrea strigilecula White.
Plicatula sp.
Camptonectes stygius White.
Camptonectes sp.
Modiola subimbricata Meek.
Trigonia sp.
Cyprina? sp.

As the McElmo formation in its type area is not known to include any marine strata, it is possible that the bed containing this fauna is older than the basal beds of the typical McElmo.

The following section was measured principally in Colt Gulch, 10 to 12 miles east of Emery, and is given in detail, except those parts near the base numbered 32 and 33:

Section of rocks of McElmo formation measured on the west flank of San Rafael Swell and the east side of Castle Valley.

Top.	Ft.	in.
1. Clay shale, gray to green, sandy, contains calcareous nodules; becomes more sandy and greenish near top	140	0
2. Sandstone, massive, in places conglomeratic	40±	
3. Sandstone, gray, medium bedded	11	4
4. Shale, similar to No. 6	13	2
5. Sandstone, gray; weathers brown; medium grained and medium bedded	10	0

[1] Gilbert, G. K., Report on the geology of the Henry Mountains, pp. 4, 5, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1877.

[2] Cross, Whitman, and Purington, C. W., U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), p. 3, 1899.

A. CONTACT OF McELMO FORMATION AND LA PLATA SANDSTONE ON THE WEST FLANK OF THE SAN RAFAEL SWELL.

1, McElmo formation; 2, contact between McElmo and La Plata; 3, La Plata sandstone.

B. LOCAL UNCONFORMITY IN THE DAKOTA SANDSTONE NORTHEAST OF FERRON.

Section of rocks of McElmo formation measured on the west flank of San Rafael Swell, etc.—Continued.

	Ft.	in.
6. Shale, gray, sandy	17	8
7. Sandstone, medium bedded; contains some shale; conglomeratic at top	11	6
8. Shale, sandy, variegated; contains thin beds of gray to brown sandstone; calcareous in places; general color brown	207	0
9. Conglomerate, gray; contains black chert and limestone pebbles, the largest 3 or 4 inches in diameter; contains bones, unidentified	15	6
10. Clay shale, gray, red, and white, with some sandstone and cone-in-cone concretion-like material alternating	48	0
11. Conglomerate, gray; contains black chert and limestone pebbles 3 inches or less in diameter; also some soft, friable sandstone	8±	
12. Sandstone, gray (probably top of Flaming Gorge formation as defined by Powell)	4	0
13. Gypsum, sandy, red, gray, and white	16	6
14. Gypsum, pink, impure; very shaly at base, very pure at top; contains cherty concretions	22	0
15. Shale, salmon-red and in places greenish gray	10	4
16. Gypsum, almost pure	10	0
17. Shale, red, sandy	1	3
18. Gypsum, somewhat impure	4±	
19. Clay, salmon-red, sandy	11	0
20. Sandstone, greenish gray, and red sandy shale alternating	20	8
21. Sandstone, red, argillaceous	5	0
22. Sandstone, gray, weathers brown, rather thin bedded	6	0
23. Sandstone and sandy shale, salmon-red, thin bedded; contains one or two lenses of calcareous sandstone 2 feet thick near top (within 25 feet); also a stratum of gypsum 6 to 8 inches thick near top	167	0
24. Sandstone, white, fine grained, ledge maker		5
25. Sandstone and sandy shale, chocolate-red in color; contains some thin-bedded sandstone near top; thin streaks of green sandy clay occur in this material	57	0
	857	4±
26. Shale, greenish gray, slightly pinkish at top, sandy	50±	
27. Sandstone, gray, thin bedded, shaly	45	0
28. Sandstone, massive, gray to white, friable	100±	
29. Sandstone, grayish green, shaly, thin bedded	18	0
30. Conglomerate; contains black chert and quartz pebbles up to 4 inches in diameter		5
	[1] 213	5±
31. Sandstone, greenish gray to white, shaly	3	0
32. Sandstone, red, massive, thin bedded	400±	

[1] This part of the section (Nos. 26 to 30, inclusive) probably corresponds to the Salt Wash sandstone member of the Green River region. See U. S. Survey Bull. 541, p. 127, 1914.

Section of rocks of McElmo formation measured on the west flank of San Rafael Swell, etc.—Continued.

	Ft.	in.
33. Sandstone, calcareous, gray in places, slightly green, thin bedded	200±	
34. Gypsum, relatively pure	30+	
35. Sandstone, red; contains many veins of gypsum	10	0
36. Gypsum, very pure	7	0
37. Sandstone, red	5	0
38. Sandstone, greenish gray, thin bedded	60	0
39. Shale and sandstone, red, thin bedded	18	0
40. Sandstone, yellowish brown, thin bedded	15	0
41. Sandstone, yellowish brown, massive	10	0
42. Sandstone, yellowish buff and maroon, thin bedded (fossils named on p. 24 collected near base of this stratum)	15	0
	773	0
	1,843	9±

CRETACEOUS SYSTEM.

DAKOTA SANDSTONE.

The Dakota sandstone is well exposed throughout the length of Castle Valley except for about 1 mile in secs. 14, 22, 23, and 27, T. 20 S., R. 8 E., 3 to 4 miles south of Ferron Creek. It has been definitely correlated with the Dakota sandstone as mapped by Richardson[1] near Mounds, in the Book Cliffs coal field. This formation was traced continuously from Mounds to Ivie Creek, a distance of about 60 miles, but south of Ivie Creek the mapping of the Dakota is only approximate. This formation also crops out in small isolated areas near Farnham, both north and south of the Denver & Rio Grande Railroad.

The Dakota consists mostly of grayish-buff sandstone, but in places is composed of interbedded sandstone, sandy shale, and conglomerate of the same color, in varying proportions. Cross-bedding is common, suggesting that the material was deposited in shallow water where currents continuously reworked it. In many places local unconformities occur within the formation. An exposure near the center of sec. 36, T. 19 S., R. 8 E., on a small northern tributary of Ferron Creek, shows that a part of the gray massive sandstone has been replaced by dark-brown cross-bedded sandstone. The line separating the two kinds of sandstone is very distinct. This phenomenon suggests that at one time an erosion channel was cut into the gray sandstone, and that later the cut was filled by sand of a different color.

[1] Richardson, G. B., Reconnaissance of the Book Cliffs coal field, between Grand River, Colo., and Sunnyside, Utah: U. S. Geol. Survey Bull. 371, pp. 12–14, pl. 3, 1909.

Plate II, *B*, is a view of this local unconformity. A thin coal bed of no economic importance is present in places near the top of the formation. A full description of this coal is given on pages 74–76. Sections of the Dakota sandstone were measured at several points along the east side of Castle Valley and are given below to show its variation in character and thickness.

Section of Dakota sandstone measured in T. 16 S., R. 11 E., 3 miles southwest of Mounds.

	Feet.
Sandstone, gray and yellow, cross-bedded, conglomeratic	7
Conglomerate; pebbles as large as 3 inches in diameter	2
Covered (probably gray argillaceous sandstone)	28
Sandstone, gray; weathers brown; massive; argillaceous in places	10
Sandstone, gray; weathers brown in places; somewhat conglomeratic; pebbles chiefly of gray clayey material	12
Covered	8
Sandstone, gray; weathers brown; massive, fine grained	8
	75

The material directly underlying the Dakota at this place consists of "lumpy" light, porous, cellular white clay. A section measured on Huntington Creek, about 25 miles southwest of this locality, shows the formation much thinner and considerably different in character:

Section of Dakota sandstone measured on Huntington Creek in sec. 4, T. 19 S., R. 9 E., about 5 miles east of Castledale.

	Ft.	in.
Sandstone, yellowish gray, somewhat friable, partly thin bedded and partly cross-bedded	22	0
Clay shale, yellowish gray	1	6
Sandstone, brownish yellow, fine grained, argillaceous	3	6
	27	0

The rocks directly underlying the Dakota sandstone at this locality consist of 300 to 500 feet of maroon to drab sandy shale, sandstone, and conglomerate. The beds of conglomerate, which occur near the base of the series, are in places calcareous and undoubtedly should be included within the McElmo formation, but their physical character in other places suggests a similarity to the Dakota.

Two or three miles southwest of the above-mentioned locality another exposure, on the south bank of Cottonwood Creek near the center of sec. 17, T. 19 S., R. 9 E., shows that the rocks have changed considerably in character and that a carbonaceous bed occurs at the top of the formation.

Section of Dakota sandstone measured on Cottonwood Creek in sec. 17, T. 19 S., R. 9 E., about 5 miles southeast of Castledale.

	Feet.	
Sandstone, yellow, saccharoidal; contains small iron concretions; lower part slightly conglomeratic	11	6
Sandstone, massive, yellow and brown, conglomeratic near base	24	0
	35	6

The carbonaceous beds are not persistent and may occupy any position in the formation. In one place near this location carbonaceous material rests on the shale underlying the Dakota sandstone.

The formation is thicker toward the southwest, as shown by the following section measured near Horn Silver Gulch in sec. 9, T. 21 S., R. 8 E., about 8 miles southeast of Ferron:

Section of the Dakota sandstone measured in sec. 9, T. 21 S., R. 8 E., about 8 miles southeast of Ferron.

	Ft.	in.
Sandstone, yellow, saccharoidal; contains small iron concretions; lower part slightly conglomeratic	11	6
Sandstone, massive, yellow and brown, conglomeratic near base	24	0
	35	6

The formation at this locality contains many spherical iron concretions. The upper part of the sandstone seems to be distinct from the underlying and more massive part, which weathers into large cubic blocks. A fine-grained thin yellow "clay-ball" conglomerate separates the two parts. Directly underlying the sandstone, unconformably at this place, are beds of shale and sandstone several feet thick containing fragmentary fossil leaves that could not be identified. This section is as follows:

Section of rocks underlying the Dakota sandstone in sec. 9, T. 21 S., R. 8 E.

	Ft.	in.
Shale, bluish gray	1	3
Sandstone, brownish gray, cross-bedded, somewhat carbonaceous	2	0
Clay shale, bluish gray; contains leaves of several species (unidentified)		8
Shale, sandy, coarse grained, conglomeratic	1	0
Shale, drab		3
Clay, white, calcareous, lenticular		2
Shale, drab, with yellow iron concretions	1	0
Shale, sandy, bluish		3
Shale, sandy, drab, yellow, and gray	1	6
	8	1

It is possible that these rocks should be included in the Dakota dstone.

About 5 miles southeast of Rochester, on the north side of Dry Wash, in the E. ½ sec. 36, T. 21 S., R. 7 E., the Dakota sandstone is much thicker and contains more conglomerate than is shown by any other section measured in this part of Castle Valley.

Section of Dakota sandstone measured in the E. ½ sec. 36, T. 21 S., R. 7 E.

	Feet.
Conglomerate, consisting mainly of quartz and black chert pebbles, 2 or 3 inches in diameter	1±
Sandstone, yellowish gray, soft, thin bedded	6
Sandstone, yellowish gray, soft, mainly thin bedded; cross-bedded in places; contains a few iron concretions stained yellow and brown	18+
Clay shale, gray, yellow, and red	3+
Sandstone, grayish yellow, indurated, massive, coarse-grained, conglomeratic in places	26
Clay shale, yellowish gray, gypsiferous	2
	56+

About 5 miles southwest of the point where this section was measured thin lenses of coal occur in the top of the Dakota sandstone. (See locations 418, 419, and 420 on Pl. XII, and p. 75.)

Another section was measured about 12 miles southeast of Emery and is given below.

Section of Dakota sandstone measured about 12 miles southeast of Emery, 3 miles south of Ivie Creek, near the west side of sec. 36, T. 23 S., R. 6 E.

	Ft.	in.
Sandstone, gray, brown wherever weathered, massive, and thin bedded; iron stained in places; contains a thin lens of shaly coal at base	36	0
Sandstone, yellowish brown; small clay balls form a thin bed of conglomerate at base	3	6
	39	6

A section of the Dakota sandstone measured near the south end of the field shows the formation to be somewhat thicker than in the vicinity of Ivie Creek, where the preceding section was measured. The character and thickness of the rocks in the Dakota sandstone at the south end of the coal field are given below.

Section of the Dakota sandstone measured in SE. ¼ sec. 25, T. 25 S., R. 4 E.

	Ft.	in.
Sandstone and bluish sandy shale alternating	30	0
Shale, brown, carbonaceous (see location 421 on p. 76)	1	0
Coal, impure		8
Shale, brown, carbonaceous		8
Sandstone (?), poorly exposed	12	0
Sandstone, white	2	6
Coal, rusty, probably impure		3
Sandstone and sandy shale, poorly exposed	12	0
Shale, coaly, very carbonaceous		8
	59	9

The Dakota sandstone is exceedingly variable in thickness and character, as is shown by the sections given above. Weathering undoubtedly accounts for some of its variation in color. The only fossils collected in this formation were the fragmentary leaves mentioned on page 28. At many places in Castle Valley evidences of an unconformity were noted at the base of the formation. This may only be apparent, however, because local unconformities as extensive as that which occurs at its base are present within the sandstone itself.

MANCOS SHALE.

GENERAL FEATURES.

The Mancos shale in Castle Valley consists of three natural subdivisions. The lowest, about 600 feet thick, is described in this report as "Shale below the Ferron sandstone member." Conformably overlying this shale is the Ferron sandstone member, which contains the coal in the southern part of Castle Valley. This member increases in thickness from about 75 feet at the north end of Castle Valley to about 800 feet at its south end. The highest subdivision is described in this report as "Shale above the Ferron sandstone member." It rests conformably on the Ferron sandstone and is about 3,000 feet thick in the vicinity of Emery. At the south end of the field it is impossible to determine its exact thickness on account of extensive faulting.

SHALE BELOW THE FERRON SANDSTONE MEMBER.

That part of the Mancos shale underlying the Ferron sandstone member ("shale of the San Rafael Swell" of Taff's classification) consists of about 600 feet of bluish-drab shale, which is rather sandy in its lower and upper parts. It probably corresponds to the Blue Gate shale and possibly includes the Tununk sandstone and the Tununk shale, as described by Gilbert[1] in his report on the Henry Mountains. Five collections of fossils were obtained in this part of the Mancos shale. All the species except one are definitely Cretaceous forms and characteristic of the lower part of the Mancos shale or basal Colorado. The species, identified by T. W. Stanton, are listed below:

Prionotropis sp.
Anomia sp.
Inoceramus n. sp., related to I. fragilis Hall and Meek.
Cardium sp.
Lucina sp.
Mactra sp.
Corbula sp.
Astarte? sp.
Ostrea sp.
Gastropod casts of two or more undetermined genera.

[1] Gilbert, G. K., Report on the geology of the Henry Mountains, pp. 4, 5, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1877.

A. FERRON SANDSTONE MEMBER OF THE MANCOS SHALE SOUTHEAST OF EMERY.

B. LOCAL UNCONFORMITY IN THE FERRON SANDSTONE MEMBER OF THE MANCOS SHALE, ABOUT 10 MILES SOUTH OF EMERY.

The greater part of this subdivision of the formation, together with a portion of the Ferron sandstone member, constitutes a "riser" or cliff, in some places 600 feet high, whereas the upper surface of the resistant overlying Ferron sandstone forms a "step" in the topography. Plate III, *A*, shows that part of the Mancos shale above discussed and also the lower part of the Ferron member. This shale weathers into bad lands along the base of the scarp.

FERRON SANDSTONE MEMBER.

The Ferron sandstone member of the Mancos shale is well developed in the vicinity of Ferron and Emery and rests conformably upon the shale above described. It crops out in the upper part of a prominent scarp which ranges from 80 to 1,000 feet in height. This member becomes thicker from a point near Mounds, where it is about 75 feet thick, to Last Chance Creek, 70 miles southwest, where it is about 800 feet thick. Local unconformities occur within the Ferron sandstone, as illustrated by Plate III, *B*. A section measured on Last Chance Creek shows this coal-bearing sandstone portion of the Mancos to be more than 800 feet thick. Eight stratigraphic sections on Plate IV show the gradual increase in thickness of the formation toward the southwest. Concretionary beds near the base of the Ferron sandstone extend from Mounds to Ivie Creek, but south of that stream concretions are not so conspicuous. In some places these spherical concretions are much more abundant than in others, being very large and numerous north of Ferron Creek. Plate V shows a typical exposure of these concretions in the vicinity of Castledale. The Ferron member of the Mancos shale in the Emery field carries the principal coal beds, all of which lie above the concretionary horizon above described. This coal, however, is of little value north of an east-west line through Emery. Carbonaceous material occurs in this sandstone for several miles north of the place (south side of T. 21 S., R. 7 E.) where the first coal of economic importance crops out.

Fossils were collected from the lower part of the Mancos shale and were identified by T. W. Stanton, who considered them indicative of "brackish-water fauna, probably of Colorado age." The fossils from the Ferron sandstone member do not conclusively prove its age, but as the fossils collected stratigraphically above and below it are definitely of Mancos age, there can be no doubt that the Ferron sandstone is also Mancos. The fossils collected on Ivie Creek about 50 feet above the base of the Ferron member, in sec. 17, T. 23 S., R. 6 E., about 8 miles south of Emery, are given below.

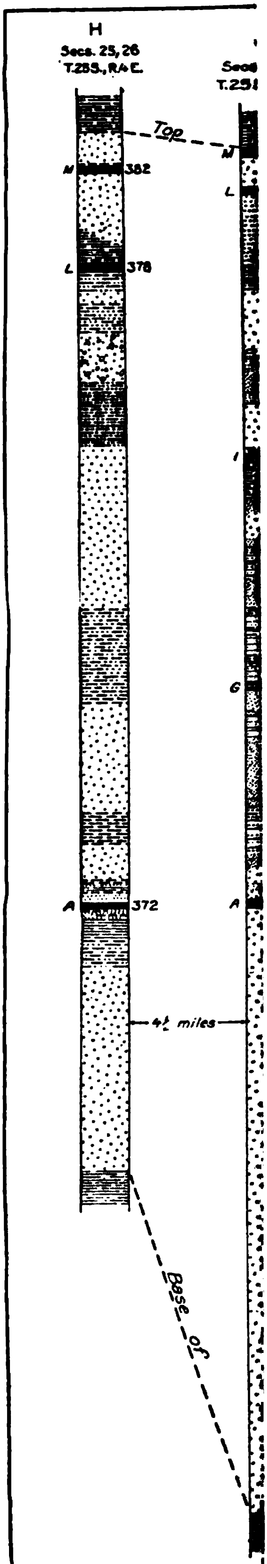
Ostrea sp.
Corbicula sp., related to C. durkeei Meek.
Turritella? sp.
Corbula sp.

The Ferron member corresponds lithologically and stratigraphically to the Blue Gate sandstone in the Henry Mountains, described by Gilbert.[1] The following section of the Ferron sandstone was measured on Ivie Creek in the north half of T. 23 S., R. 6 E., and shows the thickness and distribution of the coals in that locality:

Section of Ferron sandstone member of Mancos shale on Ivie Creek 8 miles south of Emery.

	Ft.	in.
Sandstone, gray; weathers yellowish brown; massive; contains more or less persistent layers of gray to black shale, some of which is carbonaceous. The upper 40 feet of this massive sandstone in places changes very abruptly into a slightly sandy carbonaceous shale	150±	
Bed J, location 206:		
Coal	1	2
Shale, black, carbonaceous, sandy		9
Coal	1	2
Shale, black, carbonaceous, grading upward into drab sandy shale	11	0
Bed I, location 190: Coal, weathered. This bed changes abruptly into a carbonaceous shale a short distance from the point measured	3	6
Shale, brown; weathers gray; carbonaceous, sandy	3	0
Sandstone, gray; weathers yellow and brown; massive. Beds of sandy gray to brown shale as thick as 4 feet are interstratified with the sandstone	86	0
Shale, black, carbonaceous, showing a transition upward into drab shale, which becomes sandy near top	3	0
Bed D, location 148: Coal, blocky	1	6
Shale, clayey, drab; joints iron stained; upper part very gypsiferous and carbonaceous	7	6
Bed C, location 148:		
Coal	8	4
Clay, sandy, yellow, drab at top	1	9
Coal, fair, much weathered	3	8
Sandstone, brown, carbonaceous		½
Coal, fair, much weathered	1	4
Shale, brown, carbonaceous, in places sandy	8	5
Bed B, location 132: Coal, blocky, fair	1	8
Sandstone, gray; weathers brown; medium bedded, very lenticular; in places represented by drab sandy shale	23	0
Shale, brown, carbonaceous, showing a transition upward into gray sandy shale	11	6
Bed A, location 121:		
Coal, fair, weathered	1	2
Shale, brown, carbonaceous		4
Coal, brown, fair		4
Shale, brown, sandy		6

[1] Gilbert, G. K., op. cit., pp. 4, 5.



COLUMNAR SECTIO

Bed A, location 121—Continued.

	Ft.	In.
Coal	1	2
Coal, bony		7
Coal	3	6
Shale, brown, carbonaceous, sandy		10
Sandstone, white, medium grained	1	0
Shale, brown, carbonaceous, sandy		4
Sandstone, lenticular		4
Shale, brown, carbonaceous, sandy; contains a little coal in places	4	0
Sandstone, gray, massive	57	0
Sandstone, shaly and thin bedded at base, medium bedded above	16	0
Sandstone, shaly, carbonaceous; contains thin lenses of coal and at some other places is represented by coal		5
Sandstone, thin bedded, very soft, carbonaceous	4	0
Sandstone, yellowish gray, calcareous, very fossiliferous		10
Shale, drab to yellow, sandy; upper part (1½ feet) very fossiliferous	14	6
Sandstone, yellowish gray; weathers brown; somewhat cross-bedded, ledge maker; contains thin lenses of shale in places; the top of this sandstone forms a structural terrace on which rest gravel and bowlders of basalt	40	0
	475	1½±

The above section shows an unusual thickness of coal. Taff[1] considered this sandstone ("sandstone of the Red Plateau") to be the same formation that caps Cedar Mountain (Red Plateau), 35 miles to the northeast, but the latter formation is about 1,200 feet stratigraphically below the former and probably is equivalent to a conglomerate at the base of the Henrys Fork group of Gilbert's Henry Mountains classification, or about 450 feet below the top of the McElmo formation.[2] As these formations are in some respect similar, and as Taff's work along the east side of Castle Valley was entirely reconnaissance, his conclusion that the coal-bearing sandstone south and east of Emery is the same as the formation capping Cedar Mountain naturally followed.

SHALE ABOVE THE FERRON SANDSTONE MEMBER.

The upper shaly part of the Mancos shale ("shale of Castle Valley" of Taff's classification) is about 3,000 feet thick, as determined a few miles northeast of Emery. It rests with apparent conformity upon the Ferron sandstone member and probably should be correlated with the Masuk shale of Gilbert's section of the

[1] Taff, J. A., Book Cliffs coal field, Utah, west of Green River: U. S. Geol. Survey Bull. 285, p. 291, 1906.
[2] Gilbert, G. K., op. cit., p. 4.

Cretaceous of the Henry Mountains region.[1] This subdivision of the Mancos shale is grayish drab in color, and is sandy in its lower and upper parts. The upper part in some places contains lenses of friable yellowish-gray sandstone. Fossils collected in the lower part of the shale above the Ferron sandstone member indicate that this shale is unquestionably of Mancos age. The species identified by T. W. Stanton are typical of the lower part of the Mancos and are as follows:

Inoceramus acutiplicatus Stanton?
Inoceramus labiatus Schlotheim.
Inoceramus sp.
Ostrea congesta Conrad.
Ostrea sp.
Baculites sp.
Fish scales and bones.

The topographic forms resulting from the erosion of this part of the Mancos shale are similar to those of the shale below the Ferron member. This upper shale, together with the overlying Mesaverde formation, constitutes the "riser" of the "step" formed by the overlying Mesaverde that caps the east face of the Wasatch Plateau.

MESAVERDE FORMATION.

The Mesaverde formation in this region consists of yellowish-gray sandstone, sandy shale, and coal beds. The outcrops form the upper part of the prominent east scarp of the Wasatch Plateau. From western Colorado westward along the Book Cliffs to Castle Gate, Utah, and thence southwestward along the Wasatch Plateau, the Mesaverde rocks occupy the same relative position in this extensive cliff. The formation becomes thinner to the south, as is shown by measurements at Sunnyside, Utah, where about 1,650 feet of it is exposed,[2] and at Emery, where the writer by aneroid barometer determined the thickness to be about 1,150 feet. Taff[3] called this coal formation Laramie. Regarding its thickness he said: "In the Book Cliffs the sandstone is estimated to be not less than 1,000 feet thick." Many of the sandstones included in the formation are massive and in places are 200 feet or more in thickness. The prominent coal beds occur mainly in the sandy shale portions of the formation, but as it was not examined in detail for coal little can be said as to the number and thickness of the coal beds present. In some places the coal has been burned, producing slag; in other places the burning has merely oxidized the small quantities of iron in the rocks, giving them a brick-red color. In the vicinity of Emery the principal coal beds are included within about 500 feet of strata, beginning 200 or 300 feet above the base of the formation.

[1] Gilbert, G. K., op. cit., pp. 4, 5.
[2] Unpublished data furnished by F. R. Clark.
[3] Taff, J. A., Book Cliffs coal field, Utah, west of Green River: U. S. Geol. Survey Bull. 285, pp. 291–293, 1906.

CONCRETIONS IN THE FERRON SANDSTONE MEMBER OF THE MANCOS SHALE, ABOUT 6 MILES SOUTHEAST OF CASTLEDALE.

A part of the Mesaverde formation was measured in the canyon of Ferron Creek, as shown below.

Section of part of the Mesaverde formation in Ferron Creek canyon about 12 miles slightly north of west of Ferron.

	Ft.	In.
Sandstone, yellowish gray, mainly massive	20+	
Coal	3	3
Shale, bluish gray, showing transition into carbonaceous shale	2	0
Sandstone, gray, weathers buff, fine grained	4	6
Shale, sandy and shaly sandstone, gray	5	6
Sandstone, gray, weathers buff, medium bedded; contains leaves in upper part	7	6
Shale, black, carbonaceous	1	0
Coal, weathered	4	2
Shale, brown, carbonaceous	2	6
Coal, much weathered	4	6±
Sandstone, gray, massive	25+	
Sandstone, yellowish gray, thin bedded (to level of Ferron Creek)	40+	
	119	11±
Total coal	11	11±

Fossil leaves were collected at this locality and were identified by F. H. Knowlton as *Sequoia reichenbachi* (Geinitz) Heer and fragmentary dicotyledons, which he states are "presumably Montana" in age.

It is probable that this formation is equivalent to the Masuk sandstone, about 500 feet thick, as described by Gilbert,[1] occurring in the Henry Mountains region, 80 miles southeast of Emery, where it is coal bearing and similar to the Mesaverde both lithologically and stratigraphically.

TERTIARY SYSTEM.

EOCENE SERIES.

WASATCH FORMATION.

The Wasatch formation was examined by the writer at only one locality in the area under consideration. This formation consists of alternating beds of soft varicolored sandstone and sandy shale, possibly 1,000 feet thick.

Wherever the contact between the Wasatch formation and the underlying Mesaverde formation has been carefully examined in northeastern and central Utah, evidences of an unconformity of a greater or less degree are unquestionable. On Deep Creek,[2] about

[1] Gilbert, G. K., op. cit., pp. 4, 5.

[2] Lupton, C. T., The Deep Creek district of the Vernal coal field, Uinta County, Utah: U. S. Geol. Survey Bull. 471, p. 585, 1912.

12 miles northwest of Vernal, the Wasatch formation rests upon an eroded surface of the Mancos shale. Near Vernal[1] and northeast of Blacktail Mountain[2] it lies unconformably upon the lower part of the Mesaverde, and northwest of Blacktail Mountain[3] it rests on the higher beds of the Mesaverde. In the vicinity of Castle Valley the unconformity is not so pronounced as it is farther north, along the south flank of Uinta Mountains.

At the north end of Castle Valley, near Sunnyside, about 3,700 feet[4] of strata constitute the Wasatch formation. Its base is marked by about 3 feet of yellowish-gray conglomerate. The pebbles, which are partly subangular and partly well rounded, range from sand grains to pebbles 3 inches in diameter. The matrix is a hard, well-cemented mass of fine quartz grains. The Wasatch near Emery is estimated to be 1,000 feet thick, showing a great decrease in the thickness of this formation toward the south, which is true also of the Mesaverde formation, as mentioned above. The topographic forms resulting from the erosion of the Wasatch formation are smooth slopes which present a striking contrast to the cliffs formed by rocks of the overlying Green River (?) formation and the underlying Mesaverde. No minerals of any economic importance are known to be present in the Wasatch formation of this immediate region; but near Colton and Wales, 75 to 150 miles northwest, thin coal beds are present.

GREEN RIVER (?) FORMATION.

The Green River (?) formation overlies the Wasatch and in this locality consists of about 800 feet of grayish-drab fine-grained calcareous sandstone and sandy shale, which weather white. This formation, which caps the highest part of the Wasatch Plateau west of Emery, crops out in almost vertical cliffs. Although no opportunity was afforded to determine the character of the contact at the base of the Green River (?) formation, yet it is believed to rest conformably on the Wasatch formation above described.

QUATERNARY (?) SYSTEM.

PLEISTOCENE (?) SERIES.

ALLUVIAL FANS.

Former stages of erosion are recorded by the presence of numerous remnants of alluvial fans, probably of Quaternary age. These fans fringe the east face of the Wasatch Plateau for its entire length

[1] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, p. 205, pl. 21, 1910.

[2] Lupton, C. T., The Blacktail (Tabby) Mountain coal field, Wasatch County, Utah: U. S. Geol. Survey Bull. 471, p. 607, 1912.

[3] Idem, pp. 607, 608.

[4] Determined by F. R. Clark.

and are equally numerous along the Book Cliffs, which extend southeastward and eastward into Colorado. The upper surfaces of the fans slope from the plateau at angles ranging from almost horizontal to 15°, being steepest near the cliffs. The drift or wash in these remnants is thickest near the cliffs and becomes thinner as the distance from the upland is increased. The greatest thickness of débris or fan material observed at any one place is about 50 feet.

In most places the fans seem to have been formed about the base of a somewhat dissected cliff from which intermittent streams carry large amounts of material. The positions of the alluvial fans of the first stage of erosion, represented now by remnants of fans, show conclusively that the present courses of the streams have changed but little since the time of the formation of the fans, because nowhere, so far as was observed by the writer, does a perennial stream flow through the ruins of one of these once complete erosion forms. Erosion has so thoroughly dissected these old alluvial fans that in places only a few remnants in the forms of mesas and buttes, with sloping upper surfaces, are left to mark the position of a former large fan. Along the Book Cliffs and Wasatch Plateau alluvial fans are formed with considerable rapidity (in the geologic sense) and are dissected with equal speed, because of the fact that the material on which the drift is deposited (Mancos shale) succumbs to erosion as readily as the semiconsolidated detritus of the fans themselves. The older remnants near the cliffs are from 200 to 300 feet above the surrounding country, but a few miles east of the plateau they are low and grade into the floor of Castle Valley.

Remnants of lower and more recent fans are also present, but they are much more nearly complete. The material being eroded at present is being deposited along the base of the Wasatch Plateau in the form of alluvial fans.

TERRACE GRAVELS.

Remnants of gravel-capped terraces, which probably are of the same age as the remnants of the older and higher alluvial fans above described, occur at several places along the streams that cross Castle Valley. One of the most prominent of these remnants is situated in the E. ½ sec. 26, T. 19 S., R. 8 E. It is in the form of a small mesa or butte, the top of which is a few acres in extent and lies about 250 feet above the level of Ferron Creek. The upper 10 to 15 feet of the mesa is a slightly consolidated conglomerate, the pebbles of which consist of well-rounded fragments of yellowish-gray sandstone, gray and drab limestone, quartzitic sandstone, and black cherty material, and range in size from sand grains to bowlders 1 foot in diameter. Another gravel-capped terrace remnant of probably the same age is

situated on the north side of Ferron Creek near the southwest corner of sec. 34, T. 19 S., R. 8 E. A few miles below the junction of Ferron and Cottonwood creeks, on San Rafael River at the west end of Fullers Bottom, is a terrace remnant capped with gravel, its top about 100 feet above the river level, which is believed to be of the same age as those described above. A terrace remnant at a similar height above the stream is situated on the west side of Ferron Creek about 1 mile above its mouth. Other remnants of probably the same age occur along both sides of the same creek about 5 miles above its mouth, in sec. 36, T. 19 S., R 8 E., and sec. 2, T. 20 S., R. 8 E. The pebbles composing the conglomerate in the tops of these terraces are similar in size and composition to those in the conglomerate capping the small mesa in sec. 26, T. 19 S., R. 8 E., referred to above.

Gravel-capped terrace remnants about 50 feet above the stream bed occur on each side of Huntington Creek in secs. 33 and 34, T. 18 S., R. 9 E., and secs. 3, 4, 8, and 9, T. 19 S., R. 9 E. Similar terrace remnants exist along the west side of Ferron Creek about 1 mile above its mouth, along Muddy Creek in secs. 12 and 13, T. 23 S., R. 6 E., and on the north side of Quitchuppah Creek in secs. 28, 32, and 33, T. 22 S., R. 6 E., north and northwest of the Browning mine.

The most conspicuous gravel-capped terraces in the entire field occur directly south of Ivie Creek in T. 23 S., Rs. 5 and 6 E., and T. 24 S., R. 5 E. Five of these terraces, represented by numbers from 1 to 5 on Plate XII, are in the southeastern part of T. 23 S., R. 5 E., and the highest one (No. 6) lies for the most part in secs. 4 and 9, T. 24 S., R. 5 E. The following table shows the average vertical distance between the terraces:

Approximate average vertical distance between terraces south of Ivie Creek.

No.	Feet.	Datum plane.
6	200	Above No. 5.
5	60	Above No. 4.
4	50	Above No. 3.
3	75	Above No. 2.
2	80	Above No. 1.
1	150	Above Ivie Creek.

Some of the terraces are missing in places, as shown on Plate XII, and all of them have been eroded considerably. Terrace No. 5 is more than 6 miles long, but it includes only a little more area than No. 4. The highest terrace (No. 6) is much eroded and covers approximately 1 square mile. Terraces Nos. 1, 2, and 3 cover comparatively small areas, are narrow, and are irregular in outline, but Nos. 4 and 5 have a much larger extent. In general, these terraces slope to the north at an average of 0.5° or more, but in places the upper surfaces slope as much as 4.5°, as, for example, at Windy Point, in the northern part of sec. 1, T. 24 S., R. 5 E.

Directly north of Ivie Creek the terraces are not present, except in a small area included principally in sec. 33, T. 23 S., R. 5 E.

The material composing the greater part of the gravels which cap the terraces consists principally of subangular to rounded fragments of basalt, the largest of which are 4 or 5 feet in diameter. They are derived from the extensive masses of this rock in the vicinity of Mount Hilgard and Mount Alice and to the southwest. In places as much as 20 feet of this material rests unconformably on the Mancos shale.

QUATERNARY SYSTEM.

RECENT SERIES.

The deposits of Recent age comprise the soil which forms a mantle over the greater part of the floor of Castle Valley and which is very productive wherever moisture is sufficient; the low gravel-covered terraces along streams; the low extensive compound alluvial fans along the base of the Wasatch Plateau and lower scarps; and sand dunes of small extent in T. 21 S., Rs. 7 and 8 E.

IGNEOUS ROCKS.

The east face of a basalt-capped upland which connects Mount Hilgard and Thousand Lake Mountain extends northward across secs. 9 and 4, T. 26 S., R. 4 E., and secs. 33 and 28, T. 25 S., R. 4 E., and then veers slightly to the west. No definite information regarding the thickness of these igneous rocks, which are described at length by Dutton,[1] was obtained. In addition to this basalt, a few dikes of the same material occur in sec. 34, T. 25 S., R. 4 E., and in secs. 2 and 11, T. 25 S., R. 5 E.

STRUCTURE.

GENERAL FEATURES.

The structure of Castle Valley is monoclinal and very simple. In general the strata dip slightly to the northwest, but here and there small local domes are present. The beds are probably a little more steeply inclined at the south end of the field than at any other place. The McElmo and La Plata rocks as a rule dip more steeply than the beds stratigraphically above or below them. The younger Mesaverde, Wasatch, and Green River (?) formations lie almost horizontal. Some faulting has occurred along the east scarp of the Wasatch Plateau, at the south end of the field, and on the west slope of Cedar Mountain or Red Plateau.

[1] Dutton, C. E., Report on the geology of the high plateaus of Utah, pp. 271, 280, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

UPFOLDS AND DOMES.

Small local upfolds and domes exist at several places in Castle Valley. They are, named in order from north to south, the Farnham upfold, northeast of Farnham, a flag station on the Denver & Rio Grande Railroad; the Castledale dome, on Cottonwood Creek, about 3 miles east of Castledale; the Paradise dome, south of Ferron Creek and about 8 miles east of the town of Ferron, in the northeastern part of T. 20 S., R. 8 E.; the Rochester upfold, in the southeastern part of T. 21 S., R. 7 E., 3 miles east of Rochester; and the Last Chance Creek dome, in the eastern part of T. 25 S., R. 5 E., directly east of the principal escarpment.

The Farnham upfold, an elliptical anticline situated mainly north of Price River, is 4 or 5 miles long from north to south and about 2 miles wide. Strike faults having displacements of as much as 300 feet, with the upthrown side next to the axis, occur at each side of the fold. On the west side, where the dips are steepest and the displacement is the greatest, step faults are present. Along the east side and north end the dips range from nearly zero to 10° or 15°; on the west side the strata are much more steeply inclined and the dips range from nearly zero some distance from the line of flexure to nearly vertical at one point near the southwest corner of sec. 12, T. 15 S., R. 11 E., where a prominent fault terminates and a flexure begins. The lowest rocks exposed in this eroded upfold belong to the McElmo formation.

The Castledale dome is nearly circular and is about 3 miles in diameter. The beds are horizontal in the center of the uplift but dip as much as 11° at the west side. The dome is slightly dissected by Cottonwood Creek and some of its northern intermittent tributaries.

The Paradise dome is nearly circular and is about 2 miles in diameter. The beds, however, do not dip so steeply as those in the Castledale dome, the maximum dips being 6° W. and 2° E. Erosion has exposed the upper part of the McElmo formation in this dome.

The Rochester upfold is elliptical and is about 2 miles long from northeast to southwest and 1 mile wide. The slight deformation occurring here is apparent only in the Ferron sandstone member of the Mancos shale. The maximum dip of the strata in this upfold is 15° W.; the largest eastern dip is only 6°.

The Last Chance Creek dome is larger than any of the upfolds or domes above described. Only its western and northern limits are shown on Plates X and XII. It was not studied in detail, and the dips shown on the maps are only approximate. These upfolds and domes suggest favorable structure for the accumulation of oil and gas, but there is no definite evidence that they contain these products.

A. EMERY FAULT, NORTH OF IVIE CREEK.

Indicated by heavy black line marked 1. 2, Mesaverde rocks; 3, Mancos shale.

B. PARADISE FAULT, NEAR THE SOUTHWEST END OF THE EMERY COAL FIELD.

1, Youngs Point, a few miles north of Emery; 2, fault; 3, Paradise Lake; 4, Ferron sandstone member of Mancos shale.

Many of them are so small in extent, and one, the Farnham upfold, is so much faulted, that the probabilities that they contain oil or gas in commercial quantities are very remote. Faulting, however, is not always an unfavorable condition for the accumulation of oil and gas in a dome or anticline. The Farnham upfold has been staked for oil once or twice, and it is now reported that a company contemplates drilling there.

FAULTS.

The faults in this area are strike faults—that is, their trend coincides with the strike of the beds—and are situated principally on the west side of Castle Valley near its south end, adjacent to the Wasatch Plateau. Two principal faults, the Emery fault and the Paradise fault, were mapped in considerable detail and are shown on Plates X and XII. Directly west of the Emery fault is a down-dropped block which is broken by numerous minor faults and which is in this report called the faulted zone. Although some of the faults in the faulted zone were mapped, no attempt was made to locate in detail all of them.

The Emery fault is about 20 miles long and extends in a southwesterly direction through T. 22 S., Rs. 5 and 6 E., and T. 23 S., R. 5 E., and about 5 miles south into T. 24 S., R. 5 E. It terminates a short distance south of Deer Peak, in sec. 29, T. 24 S., R. 5 E., where it intersects a short concealed east-west fault, the downthrow of which is on the north side. In the vicinity of Emery the downthrow is comparatively small, but it increases toward the southwest to about 2,000 feet near Ivie Creek, in sec. 5, T. 24 S., R. 5 E. It is believed that the Emery fault is continuous from its north end to a point 1¼ miles south of Ivie Creek. From this place to its intersection with the east-west fault referred to above its position is covered with surface wash and talus, so that its continuity is somewhat uncertain. The Emery fault in the vicinity of Ivie Creek is well shown by Plate VI, *A*.

The exact location of the east-west fault near Last Chance Creek is not known, but its existence is assumed in order to explain the structure in this immediate locality. As is indicated on both Plates X and XII, the down-faulted block of Mesaverde rocks which includes the faulted zone lies just west of Deer Peak and extends continuously as far north and northeast as Emery. A mile or more south of the assumed east-west fault beds of the Ferron sandstone member crop out along Last Chance Creek and are unbroken by even minor faults from the prominent escarpment in sec. 9, T. 25 S., R. 5 E., as far west as the Paradise fault, in sec. 1, T. 25 S., R. 4 E. These relations necessitate the assumption of a displacement of 2,500 to 3,000 feet along an east-west line.

On Deer Peak, in sec. 29, T. 24 S., R. 5 E., there are several small strike faults where the Mesaverde strata have been dragged up with the Mancos shale, which lies east of the faults. The prevailing dips are to the west.

The faulted zone west of the Emery fault is a down-dropped block of Mesaverde rocks, which has been broken into smaller blocks principally by numerous strike faults. In places it is as much as 3 miles in width, but elsewhere it is very narrow, and to the north it probably connects with the Pleasant Valley and Joes Valley faults described by Taff.[1] This faulted belt extends parallel to the Emery fault and was studied with especial care along Ivie Creek in secs. 5 and 6, T. 24 S., R. 5 E., where the strata are well exposed. Directly west of the Emery fault in this locality there is a block of Mesaverde strata from 1,000 to 1,500 feet wide, dipping about 31° W., whereas the rocks lying directly west of this block are much more nearly horizontal, dipping only 1° to 10° W. This attitude of the strata is to be expected from the fact that the faulted zone on the west side of the fault has been dropped, but those beds lying immediately west of the fault have been retarded in their descent, thus producing steep dips in the strata near the fault and gradually decreasing dips toward the west away from the fault.

Several other minor faults of slight throw cross Ivie Creek between the Emery fault and the Paradise fault, which in this locality is marked approximately by the edge of the prominent escarpment that exposes several hundred feet of that part of the Mancos shale above the Ferron sandstone member and the overlying Mesaverde strata. The faulted zone becomes less prominent south of Ivie Creek and terminates at the short east-west fault about a mile north of Last Chance Creek. The displacement due to faults within the faulted zone is much less than at the edges of this enormous down-faulted block, where the maximum displacement is approximately 2,000 feet.

The Paradise fault was mapped in detail from Ivie Creek to the south end of the field, in sec. 4, T. 26 S., R. 4 E. Its position north of Ivie Creek is given only approximately. This fault probably connects directly with the Mille Lac (Thousand Lake) fault, which was first described by Gilbert[2] in his report on the Henry Mountains. Plate VI, *B*, shows the Paradise fault near Paradise Lake, at the south end of the field. North of the east-west fault about a mile north of Last Chance Creek the Paradise fault has its downthrow on the east side, but south of that locality the downthrow is on the west side. At Last Chance Creek the strata west of the fault have been dropped 2,000 to 3,000 feet, the displacement

[1] Taff, J. A., The Pleasant Valley coal district, Carbon and Emery counties, Utah: U. S. Geol. Survey Bull. 316, pp. 343–346, pl. 20, 1907.

[2] Gilbert, G. K., op. cit., pl. 2.

equaling the thickness of the Mancos shale above the Ferron sandstone member, as is shown by the fact that the top of that sandstone on the east side of the fault is now at the level of the lower part of the Mesaverde formation on the west side of the fault. It is believed that the displacement at the south end of the field is probably 500 feet more than that at Last Chance Creek.

The faults within the Farnham upfold have been referred to above (p. 40). The principal fault on the west side of the fold extends more than a mile south of Price River. In the northern part of sec. 27, T. 15 S., R. 11 E., it strikes N. 40° E. and has a displacement of about 200 feet, the downthrow being on the east side. North of Price River the maximum throw is at least 300 feet.

A few faults exist on the west slope of Cedar Mountain or Red Plateau, near the north end of the field. One of these has a throw of possibly 200 or 300 feet and is from 2 to 4 miles in length. Other minor faults, mainly of this same type, occur at the south end of Cedar Mountain.

THE COAL.

GENERAL FEATURES.

The coal field herein described (see Pl. X, p. 74) lies east, south, and southwest of Emery. The coal, as shown by its resistance to weathering ("stocking" qualities) and its chemical composition, is a good bituminous coal. All the commercially important coal beds in this field occur in the Ferron sandstone member of the Mancos shale, which was mapped from Mounds southwestward for about 80 miles, to the south end of the field, in the northern part of T. 26 S., R. 4 E. The northernmost coal of importance appearing at the surface in the Ferron sandstone crops out in sec. 26, T. 21 S., R. 7 E. From this locality to the southern edge of the field no one coal bed was found to be continuous for the entire distance of 33 miles, but coal is present in one or more beds at every place examined, except in part of T. 22 S., R. 7 E. (see Pl. X), where the coal-bearing rocks are believed to be barren of coal of economic importance. The Ferron sandstone contains 14 coal beds in the Emery coal field. These beds are designated on Plates VIII, IX, and X by the letters A to L, La, and M. Bed A is the lowest and bed M the highest stratigraphically.

The Dakota sandstone in places contains thin lenses of coal which are of little or no economic importance compared with the coal in the Ferron sandstone member in Castle Valley and in the Wasatch Plateau field, to the west. This coal is discussed in detail under "Coal in the Dakota sandstone" (pp. 74–76).

Good coal occurs in the Mesaverde rocks that crop out in the east face of the Wasatch Plateau immediately west of the Emery coal field, but only one section of this coal (No. 422, near Paradise Lake)

was measured. Plate X (p. 74) shows the outcrop of the coa beds in the Ferron sandstone member and the prospects, mine and exposures where the coal beds were measured, as well a roads, houses, streams, faults, dikes, geologic boundaries, and th principal sandstone cliffs. The locations at which the coal was meas ured are indicated by numbers, which are arranged on the map an described in the text by townships in order from north to sout The beds are considered from the base of the coal group upwar except in the description of the coal in T. 21 S., R. 7 E., whe a coal bed is described whose correlation with any coal in the tow ship to the south is unknown. The areas of clinker indicated on th map represent localities where the coal has been burned along th outcrop. South of Ivie Creek the approximate elevations of nume ous points on the coal outcrops as well as elsewhere are shown. comparison of these altitudes will indicate something of the topo raphy and relief.

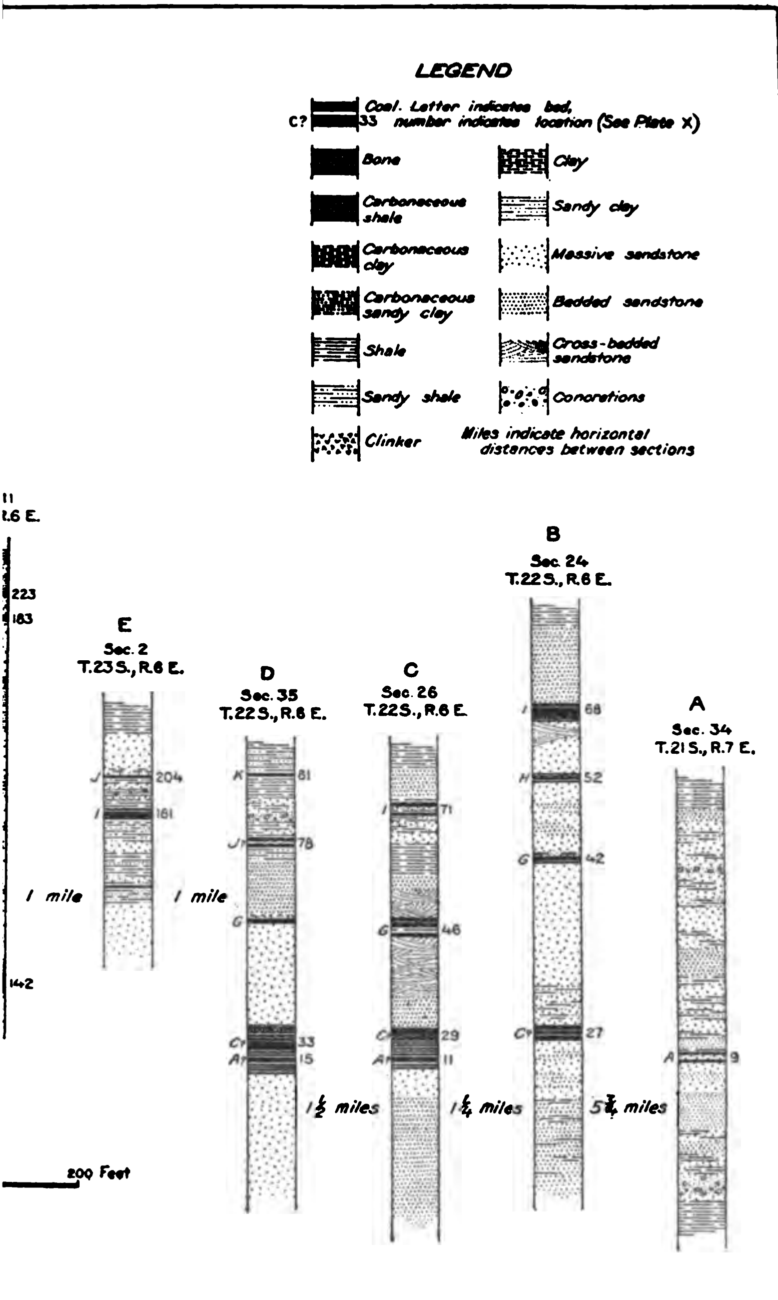
CORRELATION OF COAL BEDS IN FERRON SANDSTONE MEMBER O MANCOS SHALE.

Plate VII (p. 44) shows 18 graphic sections of beds that conta more or less coal. They are arranged on the plate from right to le in order as they appear, from northeast to southwest, along the ou crop of the coal-bearing formation. These sections show somethi of the vertical distribution, the variation in occurrence, and t change in the distances between the coal beds in the Emery fiel The localities at which these sections were measured are indicat on the map (Pl. X) by letters corresponding to those placed at t tops of the sections on Plate VII. The letters at the left of the se tions indicate coal beds. The figures at the right of the sectio refer to the coal sections measured at those places, and for the mo part shown graphically on Plates VIII and IX. The approxima distances between the places at which the sections were measured a also shown.

Some of the coal beds that occur near the middle of the Ferr sandstone on Ivie Creek (see sections K and L, Pl. VII) are eith thin or not exposed at the surface at the south end of the coal fie (see sections P, Q, and R, Pl. VII). Many of the sections do n show all the coal beds, but the lack may be due to poor exposur rather than to the absence of certain beds.

Wherever the correlation of the coal beds in the Emery field doubtful a question mark is placed after the letter at the left of th coal bed. (See Pl. VII.)

Columnar section A, measured in the NW. ¼ SE. ¼ sec. 34, T. 21 S R. 7 E., shows the presence of only one coal bed (A, coal section N 9), which is described on page 48.



ANCOS SHALE IN THE EMERY COAL FIELD.

Columnar section B, measured in the SW. ¼ NW. ¼ sec. 24, T. 22 S., R. 6 E., shows four coal beds (beds C (?), G, H, and I). Beds C (?) and I are unquestionably of commercial value at this place, but beds G and H are of little economic importance. Coal beds A and B are not exposed at the surface at this locality.

Columnar section C, measured in the NE. ¼ sec. 26, T. 22 S., R. 6 E., shows that the thickness of the rocks between beds C (?) and G is less than it is in section B, but the distance between beds G and I is about the same in both sections. Bed H is not exposed at the place where section C was measured. Bed A (?) contains 1 foot of coal and lies approximately 10 feet below bed C (?), which contains more coal than any of the other beds.

Columnar section D in a stratigraphic distance of 150 feet includes coal beds A (?), C (?), G, J (?), and K. This section was measured in the SW. ¼ SE. ¼ sec. 35, T. 22 S., R. 6 E. Bed C (?) is here also the principal bed.

Columnar section E, measured in the NW. ¼ SW. ¼ sec. 2, T. 23 S., R. 6 E., includes only two coal beds. Bed I was measured near the old Emery mine, at location 181. Bed J, at location 204, is about 15 feet stratigraphically above bed I and is of little value.

Columnar section F was measured in the SE. ¼ NW. ¼ sec. 11, T. 23 S., R. 6 E., and includes coal beds C, H, I (?), and L. Bed I (?) lies about 185 feet above bed C, and bed L is 10 feet above bed I (?). The horizon of bed H is represented by a slight indication of burning at the outcrop. Bed C is the principal bed in this locality. (See coal section 142, Pl. VIII.)

Columnar section G, measured in the NE. ¼ SW. ¼ sec. 3, T. 23 S., R. 6 E., includes coal beds C, D, and G. Bed C is the lowest coal exposed at this place. Bed D lies about 4 feet stratigraphically above bed C, and bed G, which is of little value, lies about 35 feet above bed C.

Columnar section H, measured in the N. ½ S. ½ sec. 3, T. 23 S., R. 6 E., directly across a narrow valley from the place where columnar section G was measured, shows the same coal beds as section G and in addition bed F. The thickness of the rocks between beds D and G in this section is about 10 feet greater than in columnar section G, measured across the valley. The stratigraphic distance between beds C and D is also a few feet greater in section H than in section G. Columnar sections G and H show more coal in their lower parts than any of the other columnar sections measured.

Columnar section I, measured in the NE. ¼ SE. ¼ sec. 4, T. 23 S., R. 6 E., includes coal beds A, C, F, and G and the horizon of bed I at the top. Bed D, however, may be represented by the upper bench of coal in bed C. (See coal section 146, Pl. VIII.) The horizon of

coal bed I, stratigraphically about 85 feet above bed G (location 176), is marked by a band of baked clay and slag.

Coal beds A, C, F, and G are included in columnar section J, measured in the SW. ¼ SE. ¼ sec. 33, T. 22 S., R. 6 E. The stratigraphic distance between coal beds C and F is at least 10 feet greater in this section than in columnar section I. The distance between coal beds F and G in section J is correspondingly less than in section I.

Columnar section K, measured in the W. ½ sec. 16, T. 23 S., R. 6 E., shows the position of coal beds A, C (?), G, and I. Bed G at this place contains 2 feet of unburned coal and much baked clay. The stratigraphic distance between coal beds A and C (?) is about 35 feet, which is practically the same as the distance between these beds in columnar section J, but the distance between beds C (?) and G is from 20 to 25 feet greater in section K than in section J. Bed I is the only coal shown in section K in which the entire coal bed was exposed. Beds A and C (?) are represented merely by bands of ashes and baked clay. Bed C (?) possibly should be correlated with bed B in columnar section L.

Seven coal beds are included in columnar section L, measured in secs. 7, 17, and 18, T. 23 S., R. 6 E. These are beds A, B, C, D, I, J, and M. This section shows more coal beds and a greater total thickness of coal than columnar section K, a fact which is due in part to the poor exposures at the place where section K was measured. It is believed, however, that as many coal beds exist directly north of Ivie Creek at the location of section K as there are at the location where section L was measured. The distances between bed A and bed I are practically the same in sections K and L.

Columnar section M was measured in the NW. ¼ SE. ¼ sec. 17, T. 23 S., R. 6 E., and includes coal beds A, B, C, H, I, and J. The stratigraphic distance between beds A and B is much less at this place than where columnar section L was measured. Coal bed C is represented by a bed of brown carbonaceous shale with a little coal interbedded. Beds H and I contain about the same amount of coal (a little more than 3 feet) and are separated by about 13 feet of strata.

Columnar section N includes five coal beds—beds A, B, C, I, and J—and was measured in the SW. ¼ sec. 21, T. 23 S., R. 6 E. Coal beds B and C are undoubtedly the same as those designated B and C in columnar section M. Beds I and J are definitely correlated with beds I and J in columnar sections L and M. Coal beds D, E, F, G, and H are not exposed at the locality where columnar section N was measured.

Only four coal beds, A, G, I, and L, are included in columnar section O, which was measured in lot 9, sec. 4, T. 24 S., R. 6 E. The others, beds B, C, D, E, F, H, J, and K, are not exposed and are

believed to be of little importance at this locality. Bed A is the most valuable coal bed in this section, and is stratigraphically about 95 feet below bed G. Bed I, which is second in value, lies about 120 feet above bed G, or about 55 feet below bed L.

Columnar section P, measured in the N. ½ sec. 13, T. 24 S., R. 5 E., includes seven coal beds (A, G, I, J, K, L, and M). Coal beds A and M are the most valuable, but the other beds are of no economic importance at the outcrop. Beds B, C, D, E, F, and H are not exposed where this section was measured.

Five coal beds (A, G, I, L, and M) are included in columnar section Q, which was measured in secs. 4, 5, and 9, T. 25 S., R. 5 E. Bed A is about 440 feet stratigraphically below bed L, and bed M about 20 feet above bed L. Beds G and I are of little value. The rocks separating the coal beds consist principally of sandstone and sandy shale. Coal bed M contains the greatest thickness of coal, as indicated on Plate IX by coal section No. 403.

Columnar section R, measured in secs. 25 and 26, T. 25 S., R. 4 E., shows three coal beds (A, L, and M). Beds A and M contain a little less coal here than at the location of columnar section Q, but bed L contains more coal. The distance between coal beds A and L is less and that between beds L and M greater at the location of columnar section R than at the location of section Q.

OCCURRENCE.

COAL IN THE FERRON SANDSTONE MEMBER OF THE MANCOS SHALE.

T. 21 S., R. 7 E.

Ten coal sections were measured in secs. 26, 27, 34, and 35, T. 21 S., R. 7 E., along the outcrop of one coal bed, which probably should be correlated with bed B in the townships to the south. Of these 10 coal sections Nos. 4, 5, 6, 7, and 8 are shown graphically in Plate VIII. The coal, as shown by the graphic sections, ranges in thickness from 1 foot 11 inches to 2 feet 4 inches. At each place the coal is overlain and underlain by shale, except at location 4, where it is overlain by sandstone. At locations 1, 2, 3, 9, and 10, on the north margin of the field, this coal bed is thinner than it is to the south. The sections measured at these locations are not shown graphically, but are as follows:

Sections of coal bed B (?) in T. 21 S., R. 7 E.

[In addition to those shown on Plate VIII.]

No. 1. SW. ¼ SW. ¼ sec. 26.

	Ft.	In.
Sandstone, yellowish gray, massive	35–40	
Shale, carbonaceous, sandy		8
Coal, very impure		11
Sandstone, brownish gray, argillaceous	1+	

No. 7. NE. ¼ NW. ¼ sec. 35.

	Ft.	in.
Sandstone, brown, carbonaceous	6	6
Shale, brown, sandy		1
Coal	1	3
Shale, carbonaceous, sandy		6±

No. 8. SE. ¼ NW. ¼ sec. 35.

	Ft.	in.
Sandstone, carbonaceous, grading into brown shale at base	3+	
Coal		8½
Shale, brown, carbonaceous		1+

No. 9. NW. ¼ SE. ¼ sec. 34.

	Ft.	in.
Shale, brown to black, carbonaceous	1	11
Coal, impure		1
Shale, sandy, carbonaceous, includes thin streaks of coal		4
Sandstone, brown, very carbonaceous	3	0
Shale, brown, contains a few thin bands of coal		2½
Coal, very impure		4
Shale carbonaceous		6

No. 10. NE. ¼ SW. ¼ sec. 34.

	Ft.	in.
Sandstone, yellowish gray, thin-bedded, carbonaceous in lower part	3	0
Shale, brown, carbonaceous		10
Coal	1	0
Shale, brown, carbonaceous	1+	

It is believed that the southeastern part of this township marks the northern extent of coal in the Emery coal field. No coal is exposed in the Ferron sandstone farther north in Castle Valley between this township and the Denver & Rio Grande Railroad at Mounds, although in places much carbonaceous shale is present, especially east of Molen, in secs. 16 and 21, T. 20 S., R. 8 E.

T. 22 S., R. 6 E.

Seventy-two sections were measured on the coal beds in T. 22 S., R. 6 E. The following table shows the number of sections obtained on each bed, and columnar sections B, C, and D on Plate VII show the stratigraphic distances between the beds:

Coal beds exposed in T. 22 S., R. 6 E.

	Coal sections.		Coal sections.		Coal sections.
L	82	H	51–59	D	35
K	81	G	42–50	C	17–34
J	78–80	F	37–41	A	11–16
I	60–77	E	36		

Bed A.—Coal bed A ranges in thickness from 1 foot at location 11 to 4 feet 11 inches at location 16, the average thickness being about 1 foot 7 inches. All the measurements made on the bed are shown graphically on Plate VIII, except No. 11, which is as follows:

Section of coal bed A at location 11, in the SE. ¼ sec. 26, T. 22 S., R. 6 E.

	Feet.
Shale, brown, carbonaceous, with thin lenses of coal near base	10
Coal, bony, dull	1
Shale, brown, weathers bluish	4

The shale that forms the roof of the coal in this section is the floor of bed C at location 19. The five graphic sections (Pl. VIII) show similarities in thickness of coal and in the character of the roof and floor, except at location 16, where the coal is much thicker and the roof and floor are sandstone. As in places the correlations are doubtful, the abrupt change in thickness of bed A at location 16 suggests a possibility that this section should be correlated with bed C.

Bed C.—Bed C in this township shows considerable variation in thickness and character along its outcrop from north to south, its thickness ranging from 4 feet at location 25 to about 13 feet at location 30. At location 17, in the SE. ¼ NE. ¼ sec. 25, the bed contains several inches more coal than it does at location 18, where it is about 7½ feet thick, but the arrangement of the partings in general is the same. In a distance of less than a quarter of a mile the lower 2-foot bench of coal at location 17 becomes entirely worthless, and at location 18 it is replaced by carbonaceous shale. Sections at locations 19, 20, and 21 each contain approximately 7 feet of coal, but the upper 3-inch parting at location 19 is not present at locations 20 and 21. At location 22, on the north side of Grassy Valley, in the NE. ¼ NE. ¼ sec. 24, the bed is more broken than it is at locations 20 and 21, and more nearly resembles the section at location 17 than any of the other sections between locations 17 and 22. Bed C at locations 23, 24, and 25 contains less coal than at any of the other locations mentioned, a fact which seems to indicate that the bed thins toward the south; but the section measured at location 26, in the SE. ¼ SW. ¼ sec. 13, about 1½ miles north of location 25, shows a great thickness of coal (7 feet 2 inches) compared with the section at location 25. The character of the roof changes toward the west and north from location 25, so that sandstone rests directly on the coal to a point beyond location 32. Sections at locations 26, 27, and 28 were measured along the outcrop from north to south and show that the bed is thinner on the west side as well as on the east side of Muddy Creek, toward the south. (See Pl. VIII.) This apparent decrease in the thickness ends abruptly, for at location 29, the old

Casper mine, in the SE. ¼ NW. ¼ sec. 26, bed C contains 8 feet 5 inches of coal in two benches. In mining the coal from the Casper mine only the lower bench is removed. A sample for analysis (laboratory No. 12652, p. 80) was taken from this mine. (See Pl. XI, *B*, p. 84.) At location 30, about a quarter of a mile south of the Casper mine, bed C contains 11 feet 3 inches of coal, or 2 feet 10 inches more than at location 29. The bed at location 30 is much broken by partings, but only two of them would be of special disadvantage in mining. At the next point at which the bed was measured (location 31) only 5 feet of coal in two benches is present. Both benches can be mined easily by using the 1-foot shale parting (see Pl. VIII) as a "mining seam." At location 32 the total thickness of the bed is about the same as at location 31, but more coal is present at location 32 because of the decrease in the thickness of the partings. At location 33 the bed is much broken, and probably only the lower portion will be mined. Westward from location 33 to location 34, a distance of about 2 miles, the coal bed continues fairly constant in thickness.

A careful study of the graphic sections of bed C (Pl. VIII) shows the coal to be badly split by partings and irregular in thickness. It is believed, however, that bed C is more constant in thickness than some of the beds farther south, which in places contain more coal than is exposed at any point on bed C in this township. For these reasons bed C probably holds out greater inducements for future development than some of the beds farther south which are apparently thicker.

Bed D.—Coal bed D was measured at only one place, location 35, in the SE. ¼ NE. ¼ sec. 26, where it is represented by 5 inches of coal overlain by sandstone and underlain by brown carbonaceous shale.

Bed E.—Location 36 marks the position of bed E and is the only place in the township where this coal was measured. Bed E contains 9 inches of coal, overlain and underlain by yellowish-gray massive sandstone and is 24 feet 6 inches stratigraphically above bed D.

Bed F.—Five sections of bed F were measured in this township, but the coal is of little value at every place. It is thickest at location 37, in sec. 26, where it contains 1 foot 2 inches of coal overlain by sandstone and underlain by shale, and thinnest at location 38, where thin laminæ of coal interbedded with drab shale are exposed. Five inches of coal, overlain and underlain by brown carbonaceous shale, is exposed at the horizon of bed F at location 39, in the SE. ¼ NW. ¼ sec. 26. About 150 feet north of this place the bed is entirely replaced by massive sandstone, whereas at location 40 bed F contains 6 inches of coal overlain and underlain by brown shale. At location 41 the bed contains 10 inches of fairly good coal overlain and underlain by brown carbonaceous shale.

Bed G.—Nine sections on bed G were measured in this township. It ranges in thickness from 11 inches at location 47 to 4 feet 4 inches at location 50. Five of the sections (Nos. 43, 45, 46, 49, and 50) are shown graphically in Plate VIII. The others are as follows:

Sections of coal bed G in T. 22 S., R. 6 E.

[In addition to those shown on Plate VIII.]

No. 42. SW. ¼ NW. ¼ sec. 24.

	Ft.	in.
Sandstone and shale, brown, carbonaceous; contains a few thin laminæ of coal near base	2	0
Coal, fair, weathered	1	3
Shale, brown, carbonaceous		6

No. 44. SE. ¼ NE. ¼ sec. 26.

	Ft.	in.
Shale, brown, sandy, carbonaceous		7
Coal, fair; contains a few thin laminæ of shale		5
Shale, brown, carbonaceous, sandy, with a few thin lenses of coal	2	0
Coal, weathered		11
Shale, brown, carbonaceous	6+	

No. 47. SE. ¼ SW. ¼ sec. 35.

	Ft.	in.
Shale, sandy, with thin lenses of coal		6
Coal, dull, with a little carbonaceous shale		7
Coal, fair		4
Shale, brown, carbonaceous	1+	
Coal bed		11

The correlation of all these sections with bed G is rather indefinite because of the lenticular character of the thinner coal beds in this part of the field. At location 44 bed G is broken by a 2-foot shale parting which renders the bed practically worthless for mining, but at location 45 the bed is more valuable, as shown by the section in Plate VIII. At location 48 it contains 1 foot 9½ inches of poor coal. Bed G at the last place measured (location 50, in sec. 33) is thicker (see Pl. VIII) than at any other point examined in the township, the principal bench being 3 feet 9 inches thick, with a minor bench above.

Bed H.—The coal in bed H was measured at nine places in this township—at locations 51 to 59—but only three of the coal sections (Nos. 53, 55, and 59) are shown graphically in Plate VIII. The others are described below. The maximum thickness is 3 feet at location 53. At location 51, in sec. 13, there is only 6 inches of coal overlain and underlain by sandstone, and at location 52 the bed contains 7½ inches of coal overlain and underlain by brown carbonaceous shale. The bed at location 53, in the NE. ¼ sec. 26, contains

approximately 3 feet of weathered coal overlain and underlain by sandstone, but this measurement may be incomplete. At location 54, in the E. ½ sec. 26, 1 foot 1 inch of coal, overlain by yellowish-gray sandstone and underlain by brown carbonaceous shale, is exposed on bed H, but at location 55, a short distance to the south, the bed is a little thicker, containing 1 foot 4 inches of coal, overlain and underlain by shale. The coal bed at location 56, in sec. 35, is as follows:

Section of coal bed H at location 56, in the SE. ¼ NE. ¼ sec. 35, T. 22 S., R. 6 E.

	Ft.	In.
Shale, brown, carbonaceous		1
Coal, much weathered, bony at top		9
Shale, brown, carbonaceous		3
Coal, impure, slightly shaly		4
Shale, dark, weathers gray		4
Coal, weathered, stained yellow in places		11
Bone, containing thin lenses of coal	2	0
Coal bed	2	7
Total coal	2	0

The coal at this place is of little economic importance, owing to the partings. At location 57, in sec. 35, 1 foot 2 inches of coal, overlain and underlain by brown carbonaceous shale, is exposed on bed H, and at location 58, in the same section, 1 foot 2 inches of coal is exposed, the upper part of which is slightly shaly. The floor and roof of the bed are brown carbonaceous shale. At location 59, in sec. 34, bed H contains 1 foot 8 inches of good coal, overlain and underlain by brown carbonaceous shale. Owing to the lenticular character of the coal at this horizon, exact correlations are rather difficult to make, but it is believed that the above-described sections are all on coal bed H.

Bed I.—Coal bed I was measured in this township at 18 locations, designated by Nos. 60 to 77, which are arranged in order from north to south along the outcrop. All the sections are shown graphically in Plate VIII, except No. 77, which is described below. The bed ranges in thickness from 1 foot at location 77 to 20 feet at location 75. The Moore mine, at location 60, in sec. 13, is the easternmost point at which bed I is exposed. About a quarter of a mile northwest of location 60 bed I was measured at two points in what is known as the Williams mine. (See Pl. XI, *A*, p. 84.) Coal section 61 gives the thickness of the coal at the mouth of the entry, and section 62 shows its thickness at the back end of the entry, about 200 feet S. 60° E. from location 61. The variation of the bed within a short distance is very striking, as is well illustrated by the graphic sections (Nos. 61 and 62, Pl. VIII). Near the mouth of the mine

the joints of the coal are filled with films of gypsum and sulphur. A sample was collected at location 62, and the analysis (laboratory No. 12613) is given in the table on page 80. Sections 63, 64, and 65, all measured less than a mile south of the Williams mine, suggest that bed I increases in thickness toward the south. At location 66, in sec. 13, only 4 feet 9 inches of coal is exposed, which is 3 feet less than the bed contains at location 65, a quarter of a mile to the north. Coal sections 67 and 68 show an apparent increase in thickness toward the south. Bed I rapidly deteriorates in value from location 69 toward location 71, on account of an increase in the thickness and number of partings and a decrease in the thickness of the coal. At location 72 it is of more value than at location 71, containing 3 feet of coal in one bench, overlain by shale and underlain by clay. The coal section at location 73, which is probably on bed I, seems to indicate that the bed is of little commercial importance toward the south, but at location 74, a short distance south of location 73, the bed has about the same thickness as at locations 66 and 67. It maintains this thickness for some distance along the outcrop, but at location 75, in sec. 33, at the Browning mine, it contains approximately 20 feet of coal, overlain and underlain by brown shale. This is the greatest thickness observed for any one bed in the Emery field. A sample for analysis (laboratory No. 12627, p. 80) was collected from the lower 12 feet of coal, which is the only part of the bed mined at this place. Bed I was measured at location 76, in sec. 33, but contains very much less coal here than at the Browning mine. It is only a little over 3 feet thick at location 76, as indicated in Plate VIII. Possibly the section measured at location 76 may represent a coal bed either slightly above or below bed I, as there has been considerable burning between locations 75 and 76. At location 77, in sec. 34, bed I is probably represented by only 1 foot of coal, overlain by clay of varying colors and underlain by grayish-brown sandstone. It is quite probable that the variegated claylike material overlying the coal is in large part ash, and the total thickness under cover may compare very favorably with that measured at the Browning mine (location 75). About a third of a mile northeast of the Browning mine, in sec. 33, there is an old entry on bed I which was partly filled with water at the time of the field examination. The coal was not measured at this place, but it is believed to be approximately as thick here as at the Browning mine.

Bed J.—Bed J was measured at only three locations (Nos. 78, 79, and 80) in this township. At location 78 it contains 2 feet 3 inches of coal in two benches, separated by 1 foot 2 inches of brown shale, beginning 10 inches below the top of the bed, as shown in Plate VIII.

The roof and floor of the bed are shale. At location 79, in sec. 33, the following section was measured:

Section of coal bed J at location 79, in the NE. ¼ SE. ¼ sec. 33, T. 22 S., R. 6 E.

	Ft.	In.
Sandstone, argillaceous		5
Coal, slightly shaly		5
Shale, brown	1	4
Coal		3½
Shale, brown and gray		10
Coal bed	2	½
Total coal		8½

At location 80, in sec. 33, 1 foot 3 inches of coal is exposed on bed J, which is overlain by sandstone and underlain by clay. At this place bed J is 8 feet stratigraphically above bed I.

Bed K.—Bed K is believed to be represented in this township by only one measurement, in sec. 35, where 8 inches of coal is exposed at this horizon.

Bed L.—Bed L was measured at only one place in this township, where the section is as follows:

Section of coal bed L at location 82, in the SW. ¼ NW. ¼ sec. 33, T. 22 S., R. 6 E.

	Ft.	In.
Sandstone, yellow and brown	10	0
Coal, with thin lenses of shale		4
Shale		4
Coal	1	0
Shale, gray and brown	4	0
Coal bed	1	8
Total coal	1	4

In many places in this township correlation of the coal sections is very definite, but in others it is rather doubtful, owing to the facts that some of the beds are thin and lenticular and that "burning" and talus cover have obscured the outcrops. It is believed that the correlations given above are as nearly correct as it is possible to make without drilling.

T. 22 S., R. 7 E.

In T. 22 S., R. 7 E., 34 sections were measured—Nos. 84 to 97 on coal bed C, 98 to 109 on bed F, and 110 to 117 on bed I.

Bed C.—Bed C ranges in thickness from 5 inches at location 89 to 8 feet 5 inches at location 87. Seven of the measurements made on bed C (Nos. 85, 86, 87, 88, 90, 91, and 92) are shown graphically on Plate VIII. The others are given in detail below:

Section of coal bed C at location 84, in the NE. ¼ SW. ¼ sec. 30, T. 22 S., R. 7 E.

	Ft.	In.
Sandstone, massive; weathers gray	10+	
Coal		4
Sandstone		2½
Coal	1	0
Sandstone		4
Coal bed	1	6½
Total coal	1	4

The coal at locations 85 and 86 is between 5 and 7 feet thick, but at location 87 the bed shows a marked increase in the amount of coal and also in the number of thin shale partings. At location 88, in lot 1, sec. 19, a short distance west of location 87, the total thickness of the coal bed is practically the same as at location 87, but the character and arrangement of the benches are entirely different, as indicated on Plate VIII.

Coal sections at locations 89 to 97, inclusive, in the northeastern part of the township, are correlated with bed C, because they seem to be at the same horizon as bed C elsewhere. At location 89 the bed contains only 5 inches of coal, overlain by sandstone and underlain by shale, but at locations 90, 91, and 92 the thickness ranges from 1 foot 8 inches to 2 feet 2 inches, being greatest at location 91. (See Pl. VIII.) At location 93, in sec. 10, 1 foot 1 inch of coal is exposed on bed C, but at location 94, in the same section, only 7 inches of weathered coal is exposed. Sandstone overlies and shale underlies the bed at locations 93 and 94. At location 95 the following section was measured:

Section of coal bed at C at location 95, in the NE. ¼ NE. ¼ sec. 10, T. 22 S., R. 7 E.

	Inches.
Sandstone, gray.	
Coal	3
Shale, black carbonaceous	1
Coal, slightly bony	7
Shale, black carbonaceous	10
Coal bed	11
Total coal	10

At location 96, in sec. 10, 1 foot 3 inches of coal was measured, and at location 97, in sec. 3, the bed is only 11 inches thick. The bed at each location is overlain by sandstone and underlain by shale.

Bed F.—In the southwestern part of this township bed F was measured at 12 places, which are indicated on the map (Pl. X) and on the plate of coal sections (Pl. VIII) by Nos. 98 to 109, inclusive. The character of the floor and roof and the thickness and character of the bed in this township are well shown in the graphic sections.

Bed F in this region is reasonably constant in thickness, ranging from 1 foot 9 inches at location 105 to 4 feet 10 inches at location 109, and is only locally split by partings. At location 103 the coal occurs in two benches, the lower of which probably is the same as the lower bench at location 104 and is of no economic importance. The upper bench contains 2 feet 3 inches of coal.

Bed I.—The identification of bed I in this township is uncertain, although coal sections measured at locations 110 to 117, in secs. 7 and 18, are tentatively correlated with bed I for the reason that they occur at about the same stratigraphic position as bed I elsewhere throughout the field. In this township the bed varies in thickness from 10 inches at location 115 to 1 foot 7 inches at location 112. At the Cox prospect, location 110, it contains 1 foot 4 inches of coal, overlain by sandstone and underlain by shale. Bed I in this locality is definitely known to be lenticular because it is entirely replaced by massive yellowish-gray sandstone a short distance east of this prospect. Eleven inches of coal, overlain and underlain by brown carbonaceous shale, is exposed at location 111. The coal bed at location 112 is shown graphically on Plate VIII. In the NE. ¼ SE. ¼ sec. 7, at location 113, 1 foot 1 inch of coal with shale floor and roof is exposed. At location 115, 10 inches of coal is exposed, and at location 116, in sec. 18, 1 foot 1 inch of coal, overlain by sandstone and underlain by shale, is exposed on the south side of a road leading east from Emery. Bed I contains about 1 foot of coal at location 117, in sec. 18, where sandstone underlies and shale overlies the coal.

T. 23 S., R. 6 E.

Thirteen coal beds are exposed in T. 23 S., R. 6 E., and 120 measurements of the thickness of the coal in the different beds were made. The following table shows the number of sections obtained on each bed:

Coal beds exposed in T. 23 S., R. 6 E.

	Coal sections.		Coal sections.
M	233–237	F	153–159, 162–168
L	219–232	E	152
K	216–218	D	148, 150, 151
J	204–215	C	133–138, 140–148, 160, 161
I	180–203	B	132, 139, 149
H	169, 177–179	A	118–131
G	170–176		

The usual order of the description of coal in each township, namely, by beds from the north side of the township along the outcrop to the south side, is varied for this township, the beds south of Ivie Creek, except bed I, being described before those north of that stream.

Bed A.—The thickness of bed A was measured at 14 places in this township, designated on the map (Pl. X) by Nos. 118 to 131. All these sections except Nos. 119 and 127 are shown graphically on Plate VIII. The bed ranges in thickness from 1 foot 11 inches at location 124 to 10 feet 1 inch at location 118. The overlying sandstone at locations 118 and 120 forms an excellent roof. At location 119, in sec. 16, no coal is exposed on bed A, but its horizon could be definitely traced by a streak of brown shale and sandy clay at a distance of 15 feet above the lowermost massive sandstone scarp. At location 121, in sec. 17, coal is exposed on what is believed to be bed A, but the bed is very much broken at this place and closely resembles, in the number of partings, the coal bed at location 118. The roof is brown carbonaceous shale grading upward into sandy shale and that into sandstone. At location 122, in sec. 17, the bed contains 6 feet 8 inches of coal in three benches. At location 124, in sec. 20, it contains only 1 foot 4 inches of coal in two benches, separated by 7 inches of carbonaceous shale. The correlation of coal section 124 with others here referred to bed A is doubtful on account of the greatly reduced thickness of the coal, but its stratigraphic distance above the lower sandstone scarp indicates that it is at the horizon of bed A, as heretofore stated. At location 127, in the NE. ¼ NW. ¼ sec. 21, bed A consists mainly of carbonaceous shale interbedded with some coal. The bed is about 8 feet thick, of which about 2½ feet is coal in several thin layers.

Bed B.—The coal that is assigned to bed B was measured in this township at only three places, locations 132 and 149, in sec. 17, and 139, in sec. 21. At location 132 the bed contains 1 foot 8 inches of coal, overlain by shale and underlain by sandstone, and at location 139 it contains 1 foot 9 inches of coal in two benches, separated by a 1-inch shale parting 5 inches below the top of the bed. At location 149, in the NW. ¼ SE. ¼ sec. 17, the bed is represented by only 9 inches of coal, overlain by carbonaceous shale and underlain by yellowish-gray bone.

Bed C.—Bed C was measured at 17 places in this township, indicated on the map (Pl. X) by Nos. 133 to 138, 140 to 148, 160, and 161. All the sections are shown graphically on Plate VIII, except No. 147. If the suggested correlation is correct, bed C in sec. 20 is probably lenticular and of little value. At location 134 a lens of coal of undetermined extent is of workable thickness, but at location 136 the coal is impure and of no immediate importance. Between locations 137 and 140, in secs. 21 and 28, the sections measured at the outcrop indicate that the bed is comparatively free from partings and constant in thickness, ranging from 1 foot 10 inches to 2 feet 6 inches or more except at locations 160 and 161, where an

unusual amount of coal is present. The upper 1 foot 3 inch bench at location 161 possibly corresponds to the bed as represented by coal sections 137, 138, and 140. At location 141, on an outlier in sec. 34, bed C contains 6 feet of coal in two benches, which is more than double the thickness of coal at any location on this bed in this township previously described; except 134.

In the northern part of the township bed C contains generally more coal than is exposed in the southern part. Between locations 142, in sec. 11, and 145, in sec. 3, the bed ranges from about 6 to 9½ feet, including partings which, though usually thin, separate the bed into two or more benches. These partings will probably give no serious trouble in mining. If locations 145 and 146 are at the same horizon, bed C increases in thickness very rapidly westward from location 145. The section at location 146, about a quarter of a mile distant, shows more than double the amount of coal exposed at location 145. Bed C in secs. 16 and 17 is extremely lenticular in its occurrence according to sections measured at locations 147 and 148. At location 147 no coal is exposed at the horizon of this bed, but only a carbonaceous shale band, whereas at location 148, a mile to the west, 13 feet 4 inches of coal in three benches is exposed on bed C. (See Pl. VIII.)

Bed D.—Bed D was measured at locations 148, 150, and 151, in sec. 3. At location 150 the bed contains 12 feet 6 inches of coal in six benches, and at location 151 it contains only 11 feet 1 inch in five benches. The arrangement of the benches and partings between them is shown graphically on Plate VIII. Only 1 foot 6 inches of coal is contained in bed D at location 148.

Bed E.—Location 152, in sec. 3, is the only place at which bed E was measured in this township. It contains only 10½ inches of coal overlain and underlain by shale.

Bed F.—Bed F was measured at 14 places in this township, shown on the map (Pl. X) by Nos. 153 to 159 and 162 to 168. Plate VIII gives the coal sections measured at these locations, except Nos. 153, 155, and 168. This coal is of little value along the outcrop through the western part of sec. 20 and through sec. 29, as may be inferred from the following coal sections: At location 153, in sec. 20, 1 foot 1 inch of coal on bed F contains several thin bands of shale; at location 154, near the center of sec. 29, the bed contains 1 foot 10 inches of coal (see Pl. VIII); and at location 155, near the north line of sec. 29, it contains only 8 inches of coal with a floor and roof of brown shale. Bed F along its outcrop through the eastern part of sec. 20, through sec. 21, and a small portion of sec. 28, at locations 156 to 159, contains a much greater thickness of coal (from 8½ to 9½ feet) than is exposed at any other places examined in this township. (See Pl. VIII.) The total thickness of coal south of location 162 is

greatly reduced by the splitting of the bed into two benches, the lower of which, according to the exposures, is of very little economic importance.

The exposures in secs. 3 and 4 suggest that bed F is very lenticular. At location 167, 2 feet 10 inches of coal is exposed in one bench, whereas at location 168, a few hundred feet to the west, only 6 inches of coal is exposed. The bed is overlain by shale and underlain by sandstone.

Bed G.—Bed G was examined at seven exposures in this township. The locations are shown on the map (Pl. X) and the sections are shown graphically on Plate VIII by Nos. 170 to 176.

At locations 170 and 171, near the line between secs. 29 and 32, bed G contains about 1½ feet of coal, but at location 172, near the center of sec. 29, it contains only 7 inches of coal, overlain and underlain by carbonaceous shale. At location 173, near the north line of sec. 29, bed G contains 2 feet 1 inch of coal in two benches. As may be inferred from the coal sections above given, bed G in secs. 29 and 32 is of little value, being very lenticular. No exposures were seen on the bed between locations 174 in sec. 3 and 173 in sec. 29, probably owing to poor exposures along the outcrop between those places. At locations 174 to 176, inclusive, in secs. 3 and 4 (see Pl. VIII), this bed is more constant in thickness and more persistent in occurrence than it is farther south.

Bed H.—The coal in bed H in this township was measured at locations 169, 177, 178, and 179, secs. 17, 20, and 29. The coal sections are shown graphically on Plate VIII. According to these sections, the bed shows a slight tendency to increase in thickness toward the south. It ranges from 1 foot 4 inches at location 177 to 3 feet 3 inches at location 169. No other exposures at this horizon were found, so that little is known of the occurrence of the bed in this township.

Bed I.—Bed I in this township was measured at 24 places, which are represented on the map (Pl. X) by Nos. 180 to 203. As may be inferred by a careful study of the graphic sections (Pl. VIII), bed I is very lenticular and exhibits very abrupt changes in thickness even between near-by sections. The range in thickness is from 1 foot 3 inches at location 180 to 14 feet 11 inches at location 198. At location 180, in sec. 3, the coal is overlain by gray clay shale and underlain by brown shale which contains streaks of coal. At location 181, in sec. 2, 5 feet 5 inches of coal, overlain and underlain by carbonaceous shale, is exposed on bed I. This section was measured near the Emery mine (abandoned), which at the time of the examination was closed by caving. A sample for analysis (laboratory No. 2386) was collected at the Emery mine by J. A. Taff.[1]

[1] Taff, J. A., Book Cliffs coal field, Utah, west of Green River: U. S. Geol. Survey Bull. 285, p. 294, 1906.

The measurements in this southern half of secs. 2 and 3 at locations 181, 182, 186, and 187 and in sec. 8 at location 188, all of which are believed to be on bed I, suggest a nearly east-west zone where the coal is at least twice as thick as it is on either the north or the south. South of secs. 3, 4, and 8, according to coal sections that are supposed to be on bed I, the coal is much thinner (at locations 183, 184, 185, and 189) as far south as the south line of secs. 16 and 17. Southward from this line, however, a thin lens of coal on bed I is separated from a comparatively thick one (see Pls. VIII and X) by Dog Creek, a southern tributary of Ivie Creek, flowing through secs. 31, 32, 29, 21, 20, and 16. In making the above tentative suggestion it is assumed that the correlation shown on Plate VIII is correct, but this is questionable at several locations, owing mainly to the abrupt changes in the thickness of the coal and to poor exposures between places examined. The correlation of the sections referred to bed I is based on the relation of the outcrops to other known traceable beds.

It is also possible that the entire thickness of coal on bed I is not exposed at locations 183, 184, and 185. At location 193, in sec. 20, coal "bloom" was exposed about 6 feet below the base of bed I, but it was not possible to determine the source of this "bloom." The difference in the thickness of coal between sections at locations 194, in sec. 20, and 195, in sec. 29, is due to a change in thickness of the bed, as there is no doubt about the correlation of these sections. South of location 196 bed I is concealed by alluvial deposits for a distance of a mile or more. The next measurement of the bed was made at a good exposure at location 197, in sec. 32. A sample of coal for analysis (laboratory No. 14903, p. 80) was collected from this surface exposure.

Two thin coal beds (8 inches and 4 inches thick) crop out at distances of 17 and 28 feet, respectively, above bed I at location 199, in sec. 32. The 8-inch bed probably should be correlated with coal bed J. The southernmost section showing the full thickness of coal on bed I in this township was measured at location 203, in sec. 21. The scarcity of measurements in this vicinity is due mainly to a lack of exposures at this horizon. A 1 foot 1 inch bed of coal is exposed at location 199, on the south side of a knoll near the south quarter corner of sec. 28, and is believed to represent the lower bench of bed I, the upper bench not being represented.

Bed J.—Bed J was measured at 12 places in this township, the locations of which are designated by Nos. 204 to 215. It is of little economic importance, being thin (ranging from a few inches of shale containing thin bands of coal at location 210 to 2 feet 4 inches of coal at location 206) and locally split by shale partings into two or more benches. Coal sections at locations 206 to 209, 211, and 215 are shown on Plate VIII; the others are fully described below.

At location 204, in sec. 2, bed J, which is 1 foot 1 inch thick, is overlain by 7 feet 8 inches of sandstone and shale, which in turn are overlain by a local lens of coal only 7½ inches thick. The stratigraphic distance between beds I and J at this point is 7 feet. The scarcity of sections on this coal bed is due partly to its lenticular character, partly to the extensive burning of the underlying coal bed (bed I), and partly to the presence of hill wash that covers the outcrop of the bed in places.

Little is known of this bed between locations 204 and 206, except at location 205, where it contains 1 foot 1 inch of coal in one bench, overlain and underlain by shale.

Between locations 206, in sec. 17, and 209, in sec. 20, the exposures are not so far apart and the graphic sections probably represent about the true thickness of coal. At location 210, in sec. 29, bed J is made up of brown shale containing thin bands of coal and bone and is of no economic importance. Practically nothing is known of the thickness of the coal along the outcrop between locations 210, in sec. 29, and 215, in sec. 32, a distance of about 4½ miles. Much of the coal between these points has been burned along its outcrop, and to this is probably due the scarcity of the exposures. The coal sections at locations 211 to 214, inclusive, were measured along the outcrop around an isolated tract in secs. 20, 21, and 29. The thickest of these four sections is at location 211, in sec. 29, where the coal is 1 foot 10 inches thick. The coal seems to be thinner toward the north and east from location 211. The bed contains 1 foot 2 inches of coal, underlain and overlain by shale, at location 212, in sec. 20; 9 inches of coal, with roof and floor of carbonaceous shale, at location 213, in sec. 21; and only 7 inches, with shale above and below the coal, at location 214, in sec. 29. As these measurements are well distributed and nearly surround the isolated tract, they suggest that probably bed J is of very little economic importance under this small area.

Bed K.—Three measurements on bed K were obtained in this township, the locations of which are shown on Plate X by Nos. 216 to 218. At location 216, in sec. 9, the bed contains 1 foot 2 inches of coal, with brown shale above and below it; and at locations 217, in sec. 29, and 218, in sec. 31, it contains only 4 inches of coal. Bed K in this township is thus of no economic value, as at location 216 only a very small area is underlain by the coal, and at locations 217 and 218 it is too thin to be mined. About 20 feet stratigraphically above bed K, at location 218, is a bed of carbonaceous shale containing a little coal.

Bed L.—Bed L in this township was measured at 14 places, which are designated on Plate X by Nos. 219 to 232. Plate VIII shows the sections, except Nos. 219, 222, 224, 225, 226, and 230, which are described below. The range in thickness is from 6½ inches at location

219 to 4 feet at location 228. The correlation shown on Plate VIII is doubtful in places, but it is believed that the sections here referred to bed L all occur at the same stratigraphic horizon.

Bed L in the northern part of the township, between Muddy and Quitchuppah creeks, underlies only a few isolated tracts. It is thin and much broken by partings and is of little economic importance, as is well shown by the following sections. At location 219, in sec. 3, near the horizon of bed L there are two thin beds of coal—the lower 6½ inches thick and the upper 7 inches thick—separated by about 8½ feet of sandstone, clay, and shale. The sections at locations 220 and 221 are shown graphically on Plate VIII. At location 222, in sec. 2, 9½ inches of coal on bed L is exposed in two benches separated by a 3-inch parting of drab shale. The bed is here overlain and underlain by shale.

The section at location 223 is shown on Plate VIII, except that the coal in its upper part contains several ¼-inch beds or lenses of brown shale. The following three measurements in the SE. ¼ sec. 3 suggest that bed L is of little value in a small outlier in that vicinity. At location 224 it contains only 1 foot 2½ inches of coal in two benches, separated by 1 foot 3½ inches of shale. The bed is here overlain by shale and underlain by brown clay. At location 225 it contains 1 foot 1½ inches of coal, overlain by clay and underlain by shale, and at location 226 it contains only 1 foot of coal, overlain by sandstone and underlain by shale.

The exposures in the southwestern part of the township, at locations 227 to 232, suggest that bed L is of more economic importance here than elsewhere in this township. In this area it contains from 1 foot 6 inches to 4 feet of coal. At some places the coal is badly weathered and films of gypsum fill the joints and bedding planes. The sections are all shown on Plate VIII, except that at location 230, where the coal was very poorly exposed, but where, it is believed, from 3 to 4 feet of coal is present. The bed is here overlain by sandstone and underlain by shale.

Bed M.—Bed M was measured in this township at five locations, which are indicated on Plate X by Nos. 233 to 237. Two of the sections, at locations 234 and 236, are shown graphically on Plate VIII, and the others are described below. At location 233, in sec. 11, 6 inches of coal, overlain and underlain by brown carbonaceous shale, is believed to represent bed M. The section at location 234, in sec. 7 (see Pl. VIII), shows that the bed has materially changed in character and thickness from that exposed at location 233. The change is even more striking between the near-by sections at locations 234 to 237, inclusive. At location 235, in sec. 7, the bed is practically worthless, consisting mainly of brown sandy carbonaceous shale with thin streaks of coal. At location 236, in sec. 18, it is of

more value, containing 3 feet 3 inches of coal. At location 237, in sec. 19, 1 foot of coal believed to represent bed M is exposed, with roof and floor of brown shale.

T. 24 S., R. 5 E.

The 8 coal beds exposed in T. 24 S., R. 5 E., was measured at 80 places. The table below shows the beds that are present and the numbers of the coal sections measured.

Coal beds exposed in T. 24 S., R. 5 E.

	Coal sections.		Coal sections.		Coal sections.
M	311-317	J	282-299	G	246
L	305-310	I	264-281	A	238-245
K	300-304	H	247-263		

Bed A.—The coal in bed A in this township has been more or less burned along its outcrop. The rocks overlying the coal bed south of the main branch of Willow Creek and north of the principal south branch of Willow Creek are considerably baked, and the horizon of the bed is represented by a dark-red band along the hillside, whereas north of Willow Creek the burning has been so complete that no coal remains at the surface on bed A. South of Willow Creek, however, there are a few unburned wedges or remnants of the coal which give the probable range in thickness of the coal in this township. The sections measured on bed A at locations 238 to 245 are shown graphically on Plate IX.

South of Willow Creek bed A in this township varies greatly in thickness from place to place, ranging from 9 feet 10 inches at location 241 to 14 feet 6 inches at location 240. The coal was measured in sec. 13 at location 238, where the outcrop crosses Willow Creek. The top of the bed at this place was not fully exposed, being overlain by soil, gravel, and bowlders, but it is believed that all the coal of value is shown graphically in the section on Plate IX. Southward from location 238 for a distance of about a mile the exposures on bed A are very poor, and the next measurement was obtained at location 239, in sec. 24. The base of the bed was not definitely determined, but at least 12 feet of coal is present at this place. A thin streak of bony coal, not shown on Plate IX, occurs about 2 feet below the top of the bed at location 239. At location 240, in sec. 24, about a quarter of a mile south of location 239, the bed contains 14 feet 2 inches of fairly good coal in two benches. It is believed that the entire bed is exposed here, which suggests that probably the two previous measurements given underestimate the amount of coal in the bed. Near location 242, in sec. 26, the coal bed was burning at the time of the field examination. A sample for analysis (laboratory No. 15061, p. 80) was collected from the surface prospect at location

243, in sec. 26. The sample was considerably weathered and can not give an adequate idea of the character of the coal under thick cover. Coal bed A was not measured along the outcrop toward the east, southeast, south, and southwest for a distance of 1½ to 2 miles from location 244, in sec. 24, but at location 245, in sec. 25, it contains 12 feet 9 inches of fairly good coal in two benches. South of this point in this township no sections were measured on this bed, but according to the section at location 387, in sec. 3, T. 25 S., R. 5 E., it contains 7 feet 2 inches of coal. This bed probably contains coal of workable thickness southward from location 245.

Bed G.—Bed G was measured in this township only at location 246, in sec. 24, where 5 inches of weathered coal, overlain and underlain by brown shale, is exposed.

Bed H.—Bed H was measured in this township at 17 locations, which are designated on the map (Pl. X) by Nos. 247 to 263. Six of the sections are shown on Plate IX; the others are described below. Bed H overlies bed G in this township at a stratigraphic distance of approximately 50 feet. It ranges in thickness from 8 inches at location 262 to 2 feet 7 inches at location 255. The three northernmost exposures on this bed, at locations 247, 248, and 249, in sec. 13, show it to contain about 1 foot of coal. The graphic sections on Plate IX show the thickness and character of the bed at locations 250, in sec. 13, and 251, in sec. 12. At location 252, in sec. 13, it contains 1 foot of coal, slightly bony at the base, overlain by shale and underlain by clay. The character and thickness of the bed at locations 253, in sec. 11, and 254 and 255, in sec. 14, are shown by the graphic sections on Plate IX. The distance between beds H and I at location 255 is 6 feet. About two-thirds of a mile farther east, at location 256, in sec. 13, this bed contains 1 foot 3 inches of coal, overlain and underlain by shale; and at location 257, in sec. 14, the coal bed is represented by brown to black carbonaceous shale. About a mile south of location 257 bed H at locations 258 and 259, in sec. 23, contains 1 foot 3 inches of coal, overlain by clay and underlain by shale. In the NE. ¼ SE. ¼ sec. 23, at location 260, on the west side of a deep canyon, 1 foot of coal, overlain by clay and underlain by shale, is exposed on bed H. The coal section at location 261 is shown graphically on Plate IX. Near the south boundary of sec. 23, at location 262, only 8 inches of coal is exposed on bed H which seems to be of little economic importance farther south and southwest. The southernmost place at which this bed was measured in the township is in the SW. ¼ NW. ¼ sec. 26, at location 263, where 9 inches of coal, overlain and underlain by shale, is exposed.

Bed I.—Bed I was measured in this township at 18 locations, which are designated on the map (Pl. X) by Nos. 264 to 281. Part of the sections measured are represented graphically on Plate IX;

the others are described below. The bed throughout this township is less than 2 feet in thickness, except at location 272, in sec. 11, where it is 3 feet 6 inches thick. At location 264, in sec. 13, 1 foot of coal, overlain and underlain by clay, is exposed on bed I. The sections measured at locations 265, 266, and 267, in sec. 13, are shown graphically on Plate IX. In the NE. ¼ NE. ¼ sec. 13, 1 foot 1 inch of coal, overlain by bone and shale and underlain by shale, is believed to represent bed I. The following section of this bed was made at location 268, in sec. 13:

Section of coal bed I at location 268 in the NW. ¼ NE. ¼ sec. 13, T. 24 S., R. 5 E.

	Ft.	in.
Clay, dark brown.		
Bone		2
Coal, bony, brownish black		5
Coal, weathered, stained yellow in places		8
Clay, dark reddish brown		5±
Shale, dark blue.		
Total coal	1	1

Five inches of coal, overlain and underlain by dark-brown shale, supposed to be on bed I, is exposed at location 269, in sec. 12. The coal section at location 270, in sec. 12, is shown graphically on Plate IX. At location 271, in sec. 13, the bed contains only 9 inches of dull, weathered coal, which is overlain by bone and underlain by shale. Bed I at location 272, in sec. 11, is 3 feet 6 inches thick (see Pl. IX), containing more coal than was seen at any other exposure on this bed in this township. The bed is represented by 1 foot 2 inches of coal, overlain and underlain by clay, at location 273, in sec. 14, on the south side of Willow Creek. Plate IX shows the thickness and character of bed I at location 274, in sec. 13. At location 275, in sec. 14, 1 foot 2 inches of coal is exposed, and at location 276, in sec. 23, 1 foot of weathered coal, overlain by shale and underlain by clay, represents the bed. At location 277, about 1,000 feet northeast of location 276, 1 foot of coal, overlain by clay and underlain by shale, is exposed on bed I. The coal section at location 278, in sec. 23, is shown graphically on Plate IX. The bed was measured at location 279, about a quarter of a mile farther southwest, where 1 foot of coal is exposed. Only 6 inches of coal is exposed at location 280, in sec. 23. The southernmost measurement on bed I in this township was made in sec. 26, at location 281, where 9 inches of coal, overlain by shale and underlain by dark-gray clayey sandstone, is exposed.

Bed J.—Bed J was measured in this township at 18 locations, Nos. 282 to 299. (See Pl. X.) Most of the sections are shown graphically on Plate IX. The maximum thickness is 3 feet 2 inches at location 291. At location 282, in the SE. ¼ NE. ¼ sec. 13, 9 inches of coal, overlain by clay and underlain by bone, is exposed on bed J. The

sections at locations 283 to 289, in secs. 11, 12, and 13 (see Pl. IX), show the bed to be rather irregular in thickness (from 1 foot 3 inches to 2 feet 10 inches) between these points and to occur in one bench. The upper bed of coal exposed at locations 285 and 286 (see Pl. IX) should probably be correlated with bed K. At location 290, in sec. 11, 2 feet 6 inches of coal, overlain by sandstone and underlain by dark-brown carbonaceous shale, represents bed J. The sections at locations 291 in sec. 14, and 292, in sec. 13, show the bed to be thicker than at the locations described above. (See Pl. IX.) The stratigraphic distance between beds I and J at location 293 is 9 feet. Bed J between locations 293, in sec. 14, and 296, in sec. 23, is thin and of little economic importance. At location 293 it contains 1 foot 1 inch of coal; at 294, 1 foot 2 inches; at 295, 1 foot; and at 296, only 9 inches. The roof and floor of the bed in this locality are generally shale and clay, respectively. The sections at locations 297, in sec. 23, to 299, in sec. 26, inclusive (see Pl. IX), show bed J to be of little economic importance and to deteriorate in value toward the south. It is exposed in two beds, neither of which is thick enough to be profitably mined.

Bed K.—Bed K was examined in this township at locations 300 to 304, which are indicated on the map (Pl. X). Only one section (at location 304) is shown on Plate IX; the others are briefly described below. Bed K in this township lies about 11 feet stratigraphically above the top of bed J and reaches a maximum thickness of only 1 foot 7 inches at location 304. It follows that the bed in this township is of little economic importance. There are, however, two lenses of coal, probably of small lateral extent, which are of some value, one in the vicinity of location 302, in sec. 13, and the other in the vicinity of location 304, in sec. 23. At locations 300 and 301, both in sec. 13, bed K contains 10 inches of coal. At the former place the roof and floor are bone and at the latter the roof is clay and the floor is shale. An exposure about a quarter of a mile west of location 301, believed to represent bed K, shows 1 foot 1 inch of coal having a roof and floor of carbonaceous shale. A short distance farther west 1 foot 2 inches of coal, supposedly on bed K, is exposed. At location 302, in sec. 13, there is 1 foot 2 inches of coal having clay above and bone below it. At location 303, in sec. 12, the bed contains only 8 inches of coal having a shale floor and roof.

Bed L.—Bed L was measured in this township at six locations, designated on the map (Pl. X) by Nos. 305 to 310. Three of the sections are shown on Plate IX. The bed in this township is approximately 55 feet stratigraphically above bed K and 15 feet stratigraphically below bed M. Bed L, like bed K, is of little economic importance in this township, although several exposures show a thickness of coal greater than 1 foot 3 inches. The sections at loca-

tions 305 and 306, both in sec. 13, show more than 1 foot 4 inches of coal. (See Pl. IX.) Two other exposures on bed L, one about 100 to 200 feet west of location 306 and the other at location 307, in sec. 13, each contain 11 inches of coal having a bone roof and a shale floor. At location 308, in sec. 23, the bed contains 1 foot of coal, the lower 4 inches of which is slightly bony. At location 309, in sec. 25, only 8 inches of coal is exposed. The bed at both locations is overlain and underlain by shale. In the SE. ¼ SE. ¼ sec. 24, on the east side of the ridge, 5 inches of coal is exposed which is believed to represent bed L. The southernmost exposure of bed L in this township is on the north side of Last Chance Creek, at location 310, in sec. 31, where 1 foot 8 inches of coal, overlain and underlain by dark-brown shale, is exposed.

Bed M.—Bed M in this township was measured at seven locations, which are represented on the map (Pl. X) by Nos. 311 to 317. The sections at locations 311 to 314, in secs. 13, 14, and 23, are shown on Plate IX; the remainder are described below. The maximum thickness is 5 feet 2 inches, at location 313 in sec. 14. The bed is represented by 11 inches of coal, with shale above and below, at location 315 in the SE. ¼ SW. ¼ sec. 23. At location 316, on the south fork of Willow Creek in the SE. ¼ SE. ¼ sec. 27, bed M is represented by 7 inches of bone and bony coal of no economic value. The southernmost place where this bed was measured in this township is in the SE. ¼ SW. ¼ sec. 25, at location 317, where 1 foot 1 inch of coal, overlain by clay and underlain by sandstone, is exposed. Overlying the bed at this place there is approximately 70 feet of the lower part of the shale above the Ferron sandstone.

T. 24 S., R. 6 E.

Beds A, C, F, G, H, I, J, K, L, and M are represented in T. 24 S., R. 6 E., by a total of 53 measurements, designated on the map (Pl. X) by locations 318 to 370. All the sections containing more than 1 foot 4 inches of coal are shown graphically on Plate IX by corresponding numbers. The following table indicates the numbers of the sections measured on each bed:

Coal beds exposed in T. 24 S., R. 6 E.

	Coal sections.		Coal sections.		Coal sections.
M	370	I	347–355	C	328–332
L	366–369	H	342–346	A	318–327
K	364–365	G	338–341		
J	356–363	F	333–337		

Bed A.—Bed A, which is the lowest one in the section, was measured in this township at 10 locations, which are represented on Plate X by Nos. 318 to 327. The details of the sections are shown graphi-

cally on Plate IX. The bed ranges in thickness from 1 foot 5 inches at location 325 to 13 feet 5 inches at location 319. A good example of the apparent abrupt change in thickness of bed A is furnished by coal sections 131 (Pl. VIII) and 318 (Pl. IX). The former section, showing 2 feet 3 inches of coal, was measured in sec. 33, T. 23 S., R. 6 E., and the latter, showing 8 feet 1 inch of coal, was measured in lot 8, sec. 5, T. 24 S., R. 6 E., only about 1 mile distant. There appears to be no constant rate of change in bed A in any particular direction. At location 319, in lot 9, sec. 4, east of location 318, the bed attains its greatest thickness (13 feet 5 inches) observed in this township. Less than half as much coal (5 feet 1 inch) is exposed at location 320, in lot 14, sec. 5, whereas at location 321, in lot 16, sec. 6, 9 feet 6 inches is exposed. Southwestward from location 321, however, to location 327, in sec. 18, the bed is much thinner and is badly split by partings at locations 322, 323, and 324. At various places along the north side of Willow Creek valley, in sec. 18, the horizon of bed A is marked by a considerable thickness of baked clay which locally contains some slag or fused material. When the thickness of coal in bed A at location 238, in the SW. ¼ NW. ¼ sec. 13, T. 24 S., R. 5 E., is compared with the sections last given above, it seems doubtful if the entire thickness of the coal bed is exposed at locations 322 to 327. It is believed from a careful study of the coal in this locality that bed A is valuable for several miles along the outcrop southward from Ivie Creek and probably is of some value as far south as Last Chance Creek. If it may be assumed that bed A is continuous and fairly constant in thickness, the sections measured at locations 322 to 327 probably represent only a part of bed A or possibly a "split" from it. The bed probably underlies portions of lots 3 and 4, in sec. 19, for at locations 244 and 245, in secs. 24 and 25, respectively, T. 24 S., R. 5 E., only a short distance to the west, bed A contains 12 to 14 feet of coal.

Bed C.—Coal sections 328 to 332 (see Pl. IX) represent bed C in this township and are arranged on Plate X in order from north to south along the outcrop. This bed at location 328, in sec. 8, contains 10 inches of coal, overlain by shale and clay and underlain by clay. The bed is variable in thickness and is badly split by partings in secs. 7, 8, and 18, as is shown graphically on Plate IX by sections 329 to 331. The greatest thickness is 7 feet 4 inches, at location 332, in sec. 18. Bed C in this locality is 35 feet stratigraphically above bed A.

Bed F.—Bed F was measured in this township at five locations, which are designated on Plate X by Nos. 333 to 337. The sections at locations 335 to 337 are shown graphically on Plate IX. The bed is of little economic importance in this township, as the benches of coal are thin and the intervening partings unusually thick, except

at location 337, where the bed is possibly of value, being 3 feet 6 inches thick, including partings. The section measured at location 333 is as follows:

Section of thin coal beds at the horizon of bed F at location 333, in lot 1, sec. 5, T. 24 S., R. 6 E.

	Ft.	in.
Sandstone, massive, yellowish gray; contains clay-ball concretions	30+	
Coal, blocky		6
Shale, brown, carbonaceous	2	0
Shale, brown to black; contains thin streaks of coal	2	0
Coal, impure, of variable thickness		8±
Sandstone, argillaceous and carbonaceous, brown at top; becomes less argillaceous and thin bedded near bottom	7	0
Clay, drab, grading down into brown shale	1	10
Coal, bright		7
Shale, brown, carbonaceous		6+

The base of the section at location 333 is about 60 feet above the top of bed A at location 318. An outcrop of bed G, near location 340, in sec. 5, shows that bed F contains only brown carbonaceous shale. The distance between beds F and G at this place is 42 feet. At location 334, in lot 15, sec. 6, about 4 miles along the outcrop but approximately 1¼ miles in a straight line southwest from location 333, bed F contains only 8 inches of coal, having a brown carbonaceous shale floor and roof. The distance between beds F and A at location 334 is 55 feet, as compared with 60 feet at location 333. The sections at locations 335 to 337 (see Pl. IX) shows the thickness and the character of the coal and the character of the floor and roof of bed F in secs. 7, 8, and 18.

Bed G.—Bed G is represented in this township by coal sections 338 to 341, which are described below. Three benches of coal aggregating 2 feet 8 inches are exposed at location 338, in lot 10, sec. 4. The thickness of each bench of coal and the thickness and character of the partings are shown on Plate IX. Coal section 339, measured in lot 9, sec. 4, contains 2 feet 3 inches of coal in two benches, separated by 4 inches of brown shale that begins 9 inches below the top of the bed. Brown carbonaceous shale both overlies and underlies the coal. Bed G at this place is approximately 90 feet stratigraphically above the top of bed A (Pl. IX, coal section 319). At location 340, in lot 11, sec. 5, 11 inches of coal, overlain by clay and underlain by brown shale, represents bed G, which is 65 feet below the base of bed I (Pl. IX, coal section 349). At location 341, in lot 10, sec. 5, 1 foot 1 inch of coal, overlain and underlain by brown carbonaceous shale, represents bed G, and this is the southernmost measurement obtained on this bed in this township.

Bed H.—Bed H in this township was measured at five exposures, which are designated on Plate X by Nos. 342 to 346. The exposures at locations 342 to 345 are all in sec. 6, and the character and thickness of the coal are shown on Plate IX. Southward from sec. 6 the bed was examined in the NE. ¼ SW. ¼ sec. 18, near the east end of a high ridge, where it contains only 9 inches of coal, having a shale floor and roof. The southernmost exposure examined in this township is at location 346, in sec. 18, where there is 1 foot 3 inches of coal, overlain by clay and underlain by shale.

The stratigraphic distance between beds H and A at location 347, in sec. 4, is 210 feet.

Bed I.—Coal bed I and the associated rocks were examined at nine locations, which are designated on Plate X by Nos. 347 to 355. All these sections except Nos. 350, 352, and 354 are shown graphically on Plate IX. This coal bed, if the correlation of the exposures here suggested is correct, is in this township extremely variable in thickness, as well as in the number and arrangement of the benches. The graphic sections show very well its variable character. The coal bed in secs. 4 and 5, at locations 347 to 349, seems to be relatively constant in thickness, except for the lower two benches at location 348 (see Pl. IX), which may represent a split from bed I or a local lens of small lateral extent. Bed I in the vicinity of location 356 (on bed J), in sec. 5, is represented by a band of carbonaceous shale. Toward the west, in sec. 6, at locations 350 to 353, it is of no economic value. At location 350, in lot 10, sec. 6, an exposure believed to represent bed I contains only 4 inches of coal, having a carbonaceous shale floor and roof. The section at location 351 is shown on Plate IX. At location 352, in the center of sec. 6, the bed contains 1 foot 3 inches of coal having a roof and floor of carbonaceous shale, but at location 353, only a few hundred feet to the southeast, there is only 3 inches of coal. (See Pl. IX.) No exposure was examined on bed I between the SE. ¼ sec. 6 and the SW. ¼ sec. 18. At location 354, in the N. ½ SW. ¼ sec. 18, this bed contains 11 inches of coal, having a carbonaceous shale roof and floor. The section at location 355 is shown on Plate IX.

Bed J.—Bed J in this township was measured by eight locations (Pl. X, Nos. 356 to 363), and all the sections except Nos. 361 to 363 are shown graphically on Plate IX. The exposures examined occur in secs. 5 and 6, except one at location 363, in sec. 18. The bed is of value along its outcrop from location 356 to a point between locations 359 and 360, but eastward and southward from location 360 it is of no economic value in this township. At location 361, in the NW. ¼ SE. ¼ sec. 6, the horizon of bed J is represented by a highly carbonaceous dark-brown shale 1 foot 6 inches thick. In the NW. ¼ SE. ¼ sec. 6, at location 362, 10 inches of coal, overlain by sandstone

and underlain by clay, is exposed at the horizon of the bed. The southernmost measurement on bed J in this township was made at location 363, in the NW. ¼ SW. ¼ sec. 18, where it contains 1 foot 2 inches of coal, overlain and underlain by dark carbonaceous shale. The stratigraphic distance between beds J and I in the vicinity of location 356 is 20 feet, whereas the corresponding distance in the vicinity of location 357 is only 6 feet 6 inches.

Bed K.—Bed K in this township was measured at three exposures, two of which are designated on the map (Pl. X) by Nos. 364 and 365. At location 364, in lot 10, sec. 6, it contains 1 foot 2 inches of coal, overlain and underlain by brown shale. In the NW. ¼ SW. ¼ sec. 18, 10 inches of coal, overlain by shale and sandstone and underlain by bone and sandstone, is believed to represent bed K. At location 365, also in the NW. ¼ SW. ¼ sec. 18, 8 inches of coal, overlain and underlain by bony shale, is exposed.

Bed L.—Bed L was measured at four places in this township (Pl. X, location 366 to 369). The sections are shown graphically on Plate IX. The outcrop of bed L incloses an isolated tract in secs. 4 and 5 (see Pl. X), and the bed at the exposures examined contains about 3 feet of coal. The other exposures examined on bed L are so far apart that little can be said about the character and thickness of the coal between them. Two of the exposures examined are not indicated on the map. In the NE. ¼ SW. ¼ sec. 18, near the east end of a high ridge, 9 inches of coal is exposed; and at about a quarter of a mile to the west 1 foot 8 inches of coal is exposed at the same horizon.

The stratigraphic distance between beds L and I at location 367, in sec. 4, is 57 feet and between beds J and L at location 369, in sec. 18, is 49 feet.

Bed M.—Coal section 370, measured in lot 1, sec. 7, shows that bed M contains 7 feet 11 inches of coal in two benches, the upper one 4 feet 5 inches thick, separated by 2 inches of bone. Shale both overlies and underlies the coal at this place. It is quite probable that bed M underlies the small outlying hill in the northwestern part of sec. 7 and also an irregular strip along the west side of sec. 6, where its horizon is covered by alluvium. It is known to be present also in the outlier, whose eastern part extends into sec. 18.

T. 25 S., R. 4 E.

Only three coal beds (A, L, and M) are known to be exposed in T. 25 S., R. 4 E.

Bed A.—Bed A was measured at three locations in this township, designated on Plates IX and X by Nos. 371 to 373. At each of the three exposures, which are in sec. 25, it contains about 2 feet of coal,

but southwestward from sec. 25 no outcrop was seen, and little is known of the bed in secs. 26, 34, and 35.

Bed L.—Bed L in this township was measured at seven locations (Pl. IX and X, Nos. 374 to 380). The bed ranges in thickness from 1 foot 8 inches to 5 feet 10 inches, being thinnest at locations 376 and 377 and thickest at location 378. So far as the exposures reveal the thickness and character of the coal, bed L is very irregular, as is shown graphically on Plate IX. In the SW. ¼ SE. ¼ sec. 34, at location 380, a total of 3 feet 6 inches of coal is present in three beds in a thickness of about 12 feet of strata. The two lower beds are of little value, as they are thin and widely separated by clay and bone. The upper bed, 2 feet 6 inches thick, is probably all that would be removed in mining.

Bed M.—Six measurements were obtained on bed M in this township, and are designated on Plate X by Nos. 381 to 386. All these sections are shown graphically on Plate IX, except No. 384 and the upper two benches of No. 381. In sec. 13, at location 381, 3 feet 8 inches of coal is exposed in a section of rocks 13 feet 4 inches in thickness. The two upper beds are each 6 inches thick and are separated by 4 feet of yellowish-gray sandstone. The middle bed is separated from the lowest by 5 feet 6 inches of brown shale. It is quite probable that only the lower bed of coal, which is 2 feet 8 inches thick (see Pl. IX) will be mined. At location 384 about 800 feet slightly west of south of location 383, in the NW. ¼ NW. ¼ sec. 35, 1 foot 3 inches of coal, overlain by sandstone and underlain by brown shale, represents this bed. Overlying bed M at this locality there is more sandy material than was noted in this part of the columnar section at any other place in the Emery coal field. Usually bed M is overlain directly by yellowish-drab sandy shale, becoming less sandy toward the top. One or two thin beds of limestone also were noted in the overlying rocks within a distance of 100 feet above this coal bed. At location 386 1 foot 11 inches of coal is present in 7 feet 11 inches of strata. The upper bed is 1 foot 4 inches thick and the lower one 7 inches thick. They are separated by 6 feet of light-gray to dark clay and shale.

T. 25 S., R. 5 E.

In T. 25 S., R. 5 E., 21 measurements were obtained on four coal beds. The following table shows the numbers of the coal sections measured on each bed:

Coal beds exposed in T. 25 S., R. 5 E.

	Coal sections.		Coal sections.
M	403–407	L	396–401
La	402	A	387–395

Bed A.—Coal bed A was examined in this township at nine locations (Pl. X, Nos. 387 to 395). The sections are shown graphically on Plate IX, except those at locations 393 to 395. Southwestward from sec. 3 into sec. 9 bed A shows a gradual decrease in thickness, ranging from 7 feet 2 inches at location 387 to 2 feet 6 inches at location 392. No exposures were observed in secs. 16 and 17, but farther southwest the bed is of no economic value, being too thin. In the NW. ¼ NE. ¼ sec. 20, at location 393, bed A contains only 5 inches of good coal, which is overlain and underlain by several feet of brown carbonaceous shale, containing in places thin streaks of coal. The bed is represented by 10 inches of coal with a little bone, overlain and underlain by dark-brown shale, at location 394, in the NW. ¼ NE. ¼ sec. 30. At location 395, in sec. 30, about a quarter of a mile southwest of location 394, bed A contains only 11 inches of coal, overlain by clay and underlain by shale.

Bed L.—Bed L was measured in this township at six places—Nos. 396 to 401 (see Pls. IX and X), inclusive. The graphic sections on Plate IX show the character and thickness of the bed and probably roughly represent its true condition, as the exposures are rather uniformly distributed over the northwestern part of the township. At location 398, in sec. 6, a bed which lies 10 feet below the bed shown in the plate of graphic sections (Pl. IX) contains only 3 inches of coal.

Bed La.—Only one exposure, at location 402, in sec. 3, was examined at the horizon of bed La in this township. It is believed that the coal exposed here is but a local lens or probably a split from either bed M or bed L. This section is given on Plate IX.

Bed M.—Coal bed M was measured in this township at five locations, which are designated on Plates IX and X by Nos. 403 to 407. The exposures examined are not well distributed and so perhaps do not truly represent bed M in the entire township. The bed is probably irregular in thickness and occurrence, however, as may be inferred from the sections at locations 403 to 405, which are very near together in secs. 4 and 5. At locations 406, in sec. 18, and 407, in sec. 30, the bed is more than 5 feet thick, but little is known of the coal between these exposures or between locations 406, in sec. 18, and 405, in sec. 5. It is believed, however, that only the middle bench of coal at location 404 is exposed at location 405.

T. 26 S., R. 4 E.

The coal beds of T. 26 S., R. 4 E., which are present only in secs. 2, 3, and 4, were measured at five locations—Nos. 408 to 412.

Bed A.—Bed A was measured at three places in this township, which are represented on Plates IX and X by Nos. 408 to 410. At location 409, in sec. 3, a prospect tunnel about 15 feet in length had

been made. The coal here was very much broken and distorted. The lower 3-foot bench of the lower bed was sampled for analysis (laboratory No. 15060, p. 80) at the back end of this entry. The lower coal bed, as shown on Plate IX by coal section 409, may be present elsewhere, but at locations 408 and 410 there is no evidence of its existence.

Bed B.—At location 411, in the SE. ¼ NW. ¼ sec. 3, 1 foot 1 inch of coal, overlain by clay and underlain by shale, represents bed B. The coal at this place is about 12 feet stratigraphically above bed A.

Bed L.—At location 412, in the SE. ¼ NE. ¼ sec. 4, 4 feet 4 inches of coal, overlain and underlain by shale, represents what is believed to be bed L. On account of considerable cover in places and the disturbed condition of the strata it was not practicable to obtain other measurements on any of the coal beds in this township.

COAL IN THE DAKOTA SANDSTONE.

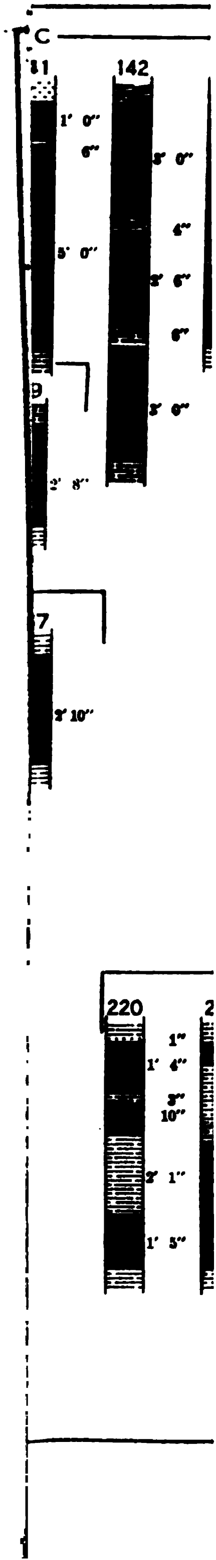
The coal in the Dakota sandstone is of some economic importance in central and eastern Utah south of the Book Cliffs,[1] but along the east side of Castle Valley it is of little value at present, and, considering the extensive deposits of coal in the Mesaverde formation in the Wasatch Plateau and Book Cliffs fields and in the Ferron sandstone member of the Mancos shale in the Emery field, it seems doubtful if the coal of Dakota age in this region will ever be mined, except possibly in a small way for domestic use by ranchers.

Sections of coal beds of Dakota age are described below in order from north to south. The locations examined are indicated on Plate XII. The northernmost exposure of coal in the Dakota sandstone examined in Castle Valley is in the SE. ¼ NW. ¼ sec. 24, T. 17 S., R. 10 E., at location 413, where there is 3 inches of coal, overlain by 2 feet or more of black carbonaceous shale and underlain by 5 feet or more of the same material. Several prospect pits, some of which are 8 feet or more in depth, have been opened in the vicinity of location 413. No evidence of coal exists at the outcrop of the Dakota, although exposures are good for about 15 miles to the southwest, but on the west side of Huntington Creek, in the NW. ¼ SW. ¼ sec. 9, T. 19 S., R. 9 E., at location 414 the following section shows the character of the rocks:

Section of coal-bearing strata in Dakota sandstone at location 414, in sec. 9, T. 19 S., R. 9 E.

	Ft.	in.
Sandstone, yellow, carbonaceous	1	0
Shale, black, very carbonaceous; contains thin streaks of coal at base	1	6
Sandstone, yellow, carbonaceous	5	0
	7	6

[1] Richardson, G. B., Reconnaissance of the Book Cliffs coal field, between Grand River, Colo., and Sunnyside, Utah: U. S. Geol. Survey Bull. 371, pp. 12–13, 1909.


C
142
1' 0"
6"
5' 0"
4"
6"
2' 8"
2' 10"
220
1"
1' 4"
10"
2' 1"
1' 5"

About 5 miles southeast of Castledale an exposure on the south side of Cottonwood Creek, in the SE. ¼ NW. ¼ sec. 17, T. 19 S., R. 9 E., at location 415, shows a lens of shale and coal interbedded, which ranges in thickness from a knife-edge to 3 feet. The lens is overlain and underlain by yellowish-gray iron-stained sandstone. About a quarter of a mile south of this place, at location 416, a prospect has been opened on a bed of bone 2 feet 5 inches thick, the top 11 inches of which contains thin layers of good coal. Three miles southwest of location 416, in the SW. ¼ NE. ¼ sec. 36, T. 19 S., R. 8 E., at location 417 on the north side of Ferron Creek, coal "bloom," which results from the weathering of a very thin bed (about half an inch) of coal, is plentiful. Southwest from this place for 18 or 20 miles the outcrop of the Dakota shows no evidence of coal, but at location 418, in the NE. ¼ NW. ¼ sec. 22, T. 22 S., R. 7 E., about 6 miles southeast of Emery, a bed of coal 1 foot 6 inches thick is exposed and contains streaks of brown carbonaceous shale. A few hundred feet to the southwest the following section was obtained:

Section of coal bed in the Dakota sandstone at location 419, in the NE. ¼ NW. ¼ sec. 22, T. 22 S., R. 7 E.

	Ft.	in.
Sandstone, brown, shaly, carbonaceous		6
Coal, bright, weathered; joints contain gypsum		9
Shale, carbonaceous; contains thin streaks of coal		3½
Coal, slightly bony		6½
Shale, brown, carbonaceous		4
Coal, bony		1½
Shale, brownish gray, carbonaceous	2	6
Coal bed	2	½
Total coal	1	5

The total amount of coal here would warrant mining where fuel is scarce, yet it seems doubtful if this bed will be utilized even as a source of domestic fuel, because much thicker beds of purer coal are present a few miles farther southwest in the Ferron sandstone member of the Mancos shale. The total coal at location 420, as shown by the following section, is practically the same as at location 419:

Section of coal bed in the Dakota sandstone at location 420, in the NW. ¼ NE. ¼ sec. 28, T. 22 S., R. 7 E.

	Ft.	in.
Conglomerate, in places replaced by sandstone		8
Coal, much weathered; contains gypsum in joints		8
Sandstone, gray, lenticular, conglomeratic		3
Coal, much weathered		7
Coal, bony, impure		2
Shale, brownish black, sandy.		
Coal bed	2	½
Total cost	1	5

Coal in the Dakota sandstone was also examined in the SE. ¼ SE. ¼ sec. 25, T. 25 S., R. 4 E., at location 421, but is of little value here, as elsewhere in Castle Valley.

Section of coal in the Dakota sandstone at location 421, in the SE. ¼ SE. ¼ sec. 25, T. 25 S., R. 4 E.

	Ft.	in.
Shale, brown, carbonaceous	1	0
Coal, apparently quite pure		8
Shale, brown, carbonaceous		8
Sandstone (?), poorly exposed	12	0
Sandstone, white	2	6
Coal, rusty, probably impure		3
Sandstone and sandy shale, poorly exposed	12	0
	29	1

COAL IN THE MESAVERDE FORMATION.

Coal of Mesaverde age is exposed in the NW. ¼ NE. ¼ sec. 22, T. 25 S., R. 4 E., at location 422. It was impossible to determine the exact thickness of the coal, owing to a fault that cuts the rocks a few feet from the exposure and has somewhat disturbed the adjacent strata. The fault has a vertical throw of about 75 feet, the downthrow being on the southwest side. At location 422 (see Pl. IX) 12 feet of coal was measured without exposing the base of the bed, but it is believed that very little coal remained unexposed at this place. The coal is overlain by 1 foot of brown shale and that by about 75 feet of sandstone and clay interbedded. Although this bed was not traced in either direction from location 422, it is believed to be the only exposure of coal of Mesaverde age included in the area shown in Plate X.

COAL IN THE MANCOS SHALE NEAR HENRY MOUNTAINS.

A belt barren of coal, 30 or 40 miles in width, separates the Emery coal field from the coal-bearing rocks of the same age in the vicinity of the Henry Mountains, to the southeast. The rocks exposed in the intervening area belong to the Vermilion Cliff, La Plata, McElmo, and Dakota formations. Gilbert[1] states: "The best outcrop was seen in the bank of the south branch of Lewis Creek where it crosses the upturned edge of the Blue Gate sandstone. The seam has a thickness of 4 feet only and is not well disposed for mining."

The writer in October, 1911, while visiting on a reconnaissance trip to the north end of the Henry Mountains, measured a flat-lying coal bed in Gilbert's Blue Gate sandstone near the center of sec. 19, T. 31 S., R. 10 E., about 2½ miles west of the base of Mount Ellen.

[1] Gilbert, G. K., Report on the geology of the Henry Mountains, p. 145, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1877.

The sandstone in which the coal occurs is believed to be the same as the Ferron sandstone member of the Mancos shale, to judge from its stratigraphic position and lithology. The section of the coal bed and associated rocks is given below:

Section of coal bed measured near center of sec. 19, T. 31 S., R. 10 E.

	Ft.	in.
Sandstone, gray, soft, massive	15+	
Sandstone, yellow and somber-colored	2	0
Coal, bright	2	1
Shale, sandy, with a little coal		1½
Coal, bright, blocky		7½
Bone		3
Coal, bright (no partings)	6	6
Sandstone, gray, argillaceous	1+	
Coal bed	9	7
Total coal	9	2½

This coal is apparently a low-grade bituminous coal and is similar to that in the vicinity of Emery described in this report. The outcrop of this bed was not traced, hence nothing definite can be said as to its extent.

Several other exposures of coal along Fremont River between the Emery field and the Henry Mountains were examined. A 2-foot bed of coal crops out on the north side of Fremont River 4 or 5 miles west of Giles. This coal occurs in the upper part of what Gilbert called the Tununk sandstone or in the lower part of his Blue Gate shale, which, with but little doubt, corresponds to that part of the Mancos shale lying beneath the Ferron sandstone member in Castle Valley. Coal is also reported near Hanksville, which is near the junction of Curtis and Fremont rivers. Coal of good quality has been mined at "The Factory," a prominent topographic feature about 6 miles north of Giles.

CHARACTER OF THE COAL.

PHYSICAL PROPERTIES.

The coal of the Emery field is pitch-black in color, but here and there thin layers of grayish-black bonelike coal are present. The coal when rubbed on unglazed porcelain gives a black streak and when pulverized in a mortar gives a black powder with possibly a slightly brownish tinge. In general the coal is bedded and has a bright vitreous luster, but parts of the same bed differ widely in appearance. In places the coal is distinctly banded, showing thin alternating bright and dull layers, while a few inches above or below the banded part the coal may be massive and either bright or

dull, and other layers a few inches thick have a dull luster and resemble cannel coal in texture. The jointing and cleavage of the coal vary somewhat, being columnar in most places but cubical in others. The fracture of the coal is remarkably even. In texture it ranges from laminated to dense, and in coherence it is comparatively brittle. The coal is hard and when struck with a hammer emits a metallic sound. When burned it gives a bituminous odor and a short yellowish-red smoky flame. The resulting ash is fine grained and gray in color. It is not known definitely whether or not the coal will coke, but when the Pishel[1] coking test was applied it showed slight coking qualities. In places where the coal is somewhat weathered, the surfaces of joints and bedding planes are partly covered with thin films of sulphur and alkaline salts. Globules of resin are present in small amounts. That the coal has good stocking qualities is inferred from the reports of ranchers and others who use it and from the condition of the walls of country banks and prospect drifts that have been exposed to weathering for many years.

CHEMICAL PROPERTIES.

Three samples for analysis were collected in the Emery coal field during the field season of 1911. Two of these (laboratory Nos. 12613 and 12627) were taken from coal bed I. Sample 12613 was collected from what is locally known as the Williams mine, at location 62, in the SE. ¼ SW. ¼ sec. 12, T. 22 S., R. 6 E., on the north side of Muddy Creek; sample 12627 was taken at the Browning mine, at location 75, in the NE ¼ SW. ¼ sec. 33 of the same township on Quitchuppah Creek. Taff, in 1905, collected a sample (laboratory No. 2386, also shown in table, p. 80) from the Emery mine (location 181, in sec. 2, T. 23 S., R. 6 E.), which is also on bed I. The other sample taken in 1911 (laboratory No. 12652) represents coal bed C and was collected at the Casper mine, at location 29, in the SE. ¼ NW. ¼ sec. 26, T. 22 S., R. 6 E., on a minor western tributary of Muddy Creek.

Three additional samples for analysis were collected during the field season of 1912 in the part of the coal field south of Ivie Creek, but owing to the lack of prospecting these samples are considerably weathered. At location 197, in the SW. ¼ SW. ¼ sec. 32, T. 23 S., R. 6 E., a sample (laboratory No. 14903) was collected under a sandstone ledge at a surface prospect on coal bed I. Laboratory No. 15061 represents a sample collected at location 243, in the SE. ¼ NE. ¼ sec. 26, T. 24 S., R. 5 E., from a surface prospect on coal bed A. In the SW. ¼ NW. ¼ sec. 3, T. 26 S., R. 4 E., at location 409, a sample (laboratory No. 15090) was collected from the lower 3

[1] Pishel, M. A., A practical test for coking coals: Econ. Geology, vol. 3, pp. 265–275, 1908.

feet of coal in a short prospect drift on bed A. As the drift is only about 15 feet long and was opened several years ago the sample undoubtedly represents weathered coal.

An effort was made to obtain samples as nearly unweathered as possible by removing a foot or more of the surface of the coal. It is believed, however, that notwithstanding the care taken, analyses 12613 and 12652 represent slightly weathered coal. These samples were collected from mines in which air could circulate freely, but sample 12627, collected from the Browning mine, which was closed so that circulation of the air was at a minimum, is considered to be practically unweathered. An ultimate analysis, which shows accurately the amount of each chemical element in the coal, was made of sample 12627 in addition to the proximate analysis and calorific determinations. The analyses of the other samples collected are only proximate but include calorific determinations with the exception of No. 2386, collected by Taff in 1905.

A proximate analysis is much simpler than an ultimate analysis. In the former the coal is treated in such a way as to determine the amounts of moisture, volatile matter (gases), fixed carbon, and ash. Usually the amount of sulphur contained in the coal is ascertained. In the ultimate analysis the exact amounts of the elements constituting the coal are determined. A calorific determination of the coal is usually made in both kinds of analyses in order to ascertain its heating value, which is expressed in terms of calories[1] and British thermal units.[2]

In sampling a coal bed a fresh face of the coal is chosen where possible and all surface impurities are removed. A channel is cut perpendicularly across the face of the coal bed from roof to floor of such size as to yield not less than 5 pounds for each foot of coal in the bed. Partings more than three-eighths of an inch in thickness are discarded. An oilcloth is generally used to catch the coal as it falls from the channel and to prevent moisture and impurities from being mixed with the sample. The coal is then pulverized, thoroughly mixed, quartered, opposite quarters discarded, and the remainder remixed. This process is continued until the sample is reduced to about 1 quart, which is sent in an air-tight can to the chemical laboratory of the Bureau of Mines at Pittsburgh for analysis.

The accompanying table of analyses shows the composition of all the samples collected in the field and the heating value of all except one (No. 2386).

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[1] A calorie is the quantity of heat required to raise the temperature of a gram of pure water 1° C. at or about 4° C.

[2] A British thermal unit (B. t. u.) is the quantity of heat required to raise the temperature of 1 pound of water 1° F. at or near the temperature of maximum density (39.1° F.).

Analyses of coal samples from the Emery coal field, Emery and Sevier counties, Utah.

[Made at the Pittsburgh laboratory of the Bureau of Mines, A. C. Fieldner, chief chemist.]

Bed.	Location.				No. on plates.	Laboratory No.	Air-drying loss.	Form of analysis.	Proximate.				Ultimate.					Heating value.	
	Quarter.	Sec.	T. S.	R. E.					Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calories.	British thermal units.
I	SW	12	22	6	62	12613	0.9	A	4.0	41.8	42.6	11.6	4.7					6,660	11,990
								B	3.1	42.2	43.0	11.7	4.7					6,720	12,100
								C		43.6	44.3	12.1	4.9					6,935	12,480
								D		49.6	50.4		5.5					7,890	14,200
I	SW	33	22	6	75	12627	.3	A	4.0	40.9	49.2	5.93	.39	5.52	73.02	1.25	13.89	7,205	12,960
								B	3.6	41.0	49.4	5.95	.39	5.51	73.24	1.25	13.66	7,225	13,000
								C		42.6	51.2	6.17	.41	5.29	76.01	1.30	10.82	7,500	13,500
								D		45.4	54.6		.44	5.64	81.01	1.39	11.52	7,990	14,380
I	SW	2	23	6	181	2386	.8	A	5.1	36.7	50.4	7.8	2.1						
								B	4.3	37.0	50.9	7.8	2.1						
								C		38.7	53.1	8.2	2.2						
								D		42.1	57.9		2.4						
I	SW	32	23	6	197	14903	8.5	A	16.7	34.3	41.9	7.1	1.1					5,275	9,500
								B	8.9	37.5	45.8	7.8	1.2					5,705	10,380
								C		41.2	50.3	8.5	1.3					6,330	11,400
								D		45.0	55.0		1.5					6,920	12,460
C	NW	26	22	6	29	12652	1.8	A	5.2	39.1	41.6	14.1	.8					6,265	11,270
								B	3.5	39.8	42.4	14.3	.8					6,380	11,480
								C		41.2	43.9	14.9	.9					6,605	11,890
								D		48.4	51.6		1.0					7,765	13,970
A	NE	26	24	5	243	15061	11.6	A	18.4	33.9	42.2	5.5	.4					5,270	9,490
								B	7.7	38.3	47.7	6.3	.5					5,960	10,730
								C		41.5	51.7	6.8	.5					6,460	11,630
								D		44.5	55.5		.5					6,930	12,480
A	NW	3	26	4	409	15090	17.0	A	23.6	32.6	33.2	10.6	2.9					4,345	7,820
								B	7.9	39.3	40.1	12.7	3.5					5,235	9,430
								C		42.7	43.5	13.8	3.8					5,685	10,230
								D		49.5	50.5		4.4					6,600	11,880

12618. Collected at the back end of the Williams mine (location 62, Pls. VIII and X), in the SE. ¼ SW. ¼ sec. 12, T. 22 S., R. 6 E. The coal was possibly slightly weathered.

12627. Browning mine (location 75, Pls. VIII and X), in the NE. ¼ SW. ¼ sec. 33, T. 22 S., R. 6 E.. The sample was taken from the lower 12 feet of coal bed I, which is 20 feet thick at this place. The sample probably represented practically fresh coal.

2386. Collected by J. A. Taff[1] in 1905 from the Emery mine (location 181), in the NW. ¼ SW. ¼ sec. 2, T. 23 S., R. 6 E., at the back end of a 50-foot drift which was inaccessible in 1911.

14903. Surface prospect (location 197, Pls. VIII and X) in the SW. ¼ SW. ¼ sec. 32, T. 23 S., R. 6 E. This sample was collected under a sandstone ledge which protected the coal somewhat. About 2 feet of the outer coal was removed in order to obtain a more nearly fresh sample. It is believed, however, that this sample was much weathered.

12652. Casper mine (location 29, Pls. VIII and X), in the SE. ¼ NW. ¼ sec. 26, T. 22 S., R. 6 E. The sample was collected from the lower 7 feet 2 inches of the bed at a point about 250 feet northwest from the mouth of the entry. The coal was probably slightly weathered.

15061. Surface prospect (location 243, Pls. IX and X) in the SE. ¼ NE. ¼ sec. 26, T. 24 S., R. 5 E. The sample was collected from the lower 11 feet 3 inches of the bed, excluding the 3-inch bone parting about 2 feet 9 inches above the base of the coal. The coal at this place if unweathered would probably compare favorably in calorific value with laboratory No. 12627.

15090. Prospect (location 409, Pls. IX and X) in the SW. ¼ NW. ¼ sec. 3, T. 26, S., R. 4 E. The sample was collected at the back end of a 15-foot drift from the lower 3-foot bench of coal. The analysis shows that it is much weathered and contains an excess of moisture.

In the table the analyses are given in four forms, marked A, B, C, and D. Analysis A represents the composition of the sample as it came from the mine. This form is not well suited for comparisons, for the amount of moisture in the sample as it comes from the mine is largely a matter of accident and consequently analyses of the same coal expressed in this form may vary widely. Analyses B represents the condition of the sample after it has been dried at a temperature slightly above normal room temperature until its weight becomes constant. This form of analysis is best adapted for general purposes of comparison. Analysis C represents the theoretical condition of the coal after all the moisture has been eliminated. Analysis D represents the coal after all moisture and ash have been theoretically removed. This is supposed to represent the true coal substance free from the most important impurities. Forms C and D are obtained from the others by recalculation.

In the analytical work it is not possible to determine the proximate constituents of coal or lignite with the same degree of accuracy as the ultimate constituents. Therefore the air-drying loss, moisture, volatile matter, fixed carbon, and ash are given to one decimal place

[1] Taff, J. A., Book Cliffs coal field, Utah, west of Green River: U. S. Geol. Survey Bull. 285, pp. 294, 301, 1906.

sample (laboratory No. 12613) taken at the back end of the entry (location 62) shows a heating value of 12,100 British thermal units on the air-dried basis. Probably 600 or 700 short tons of coal has been removed from this mine. The mouth of the mine is shown in Plate XI, *A*.

CASPER MINE.

One of the oldest mines in this field, known locally as the Casper mine, is on coal bed C on a tributary of Muddy Creek in the SE. ¼ NW. ¼ sec. 26, T. 22 S., R. 6 E. (location 29, Pl. X), about 4 miles southeast of Emery. The coal bed at this place strikes N. 5° or 6° E. and dips about 2° W. Those mining coal here have left pillars here and there between great irregular cavelike rooms, some of which are large enough for a team and wagon to turn in them. It has been the custom to load the wagons in the mine at the faces of the entry and rooms, thus avoiding any mine haul and the construction of a loading tipple. Owing to the irregular shape of the mine cavity, it is difficult to estimate the amount of coal removed, but it is believed that 1,000 to 2,000 tons has been taken from the Casper mine. A sample (laboratory No. 12652), which shows 11,480 British thermal units on the air-dried basis, was collected at a point about 250 feet northwest of the mine mouth. The coal bed has a good sandstone roof and requires very little support. Plate XI, *B*, shows the conditions at the mouth of the Casper mine.

EMERY MINE.

The Emery mine (location 181, Pl. X), in the NW. ¼ SW. ¼ sec. 2, T. 23 S., R. 6 E., was inaccessible in 1911 on account of caving. Some coal is mined from the same bed (bed I) at a surface exposure near the head of a small ravine directly south of the mouth of the old mine. Two entries have been driven—one 20+ feet and the other 50+ feet long. Taff,[1] who collected a sample from this "country bank" in 1905, states: "A drift has been driven 50 feet on the coal and two rooms have been turned." The analysis (laboratory No. 2386) made from the sample collected by Taff at this place is republished in the table of analyses on page 80 in order that all analyses made from coals in the Emery coal field may appear together. It is estimated that at least 1,000 tons of coal has been removed from the Emery mine.

BROWNING MINE.

In 1881 Philip Pugsley opened a prospect on the outcrop of coal bed I in the NE. ¼ SW. ¼ sec. 33, T. 22 S., R. 6 E. (location 75, Pl. X) on the east side of Quitchuppah Creek and directly south of the mouth of Dipping Vat Creek. This mine, which supplies the

[1] Taff, J. A., Book Cliffs coal field, Utah, west of Green River: U. S. Geol. Survey Bull. 285, p. 301, 1906.

A. WILLIAMS MINE, ON COAL BED I, ABOUT 3 MILES EAST OF EMERY.

B. CASPER MINE, ON COAL BED C, ABOUT 4 MILES SOUTHEAST OF EMERY.

greater part of the fuel for the town of Emery and the ranchers living near by, is known locally as the Browning mine because it is under the management of Ira R. Browning, of Castledale. The coal bed at this place is 20 feet thick, as shown by section 75 (Pl. VIII). The entry bears N. 85° E. for a distance of 165 feet. One room, about 40 feet in length, has been turned to the north at a point about 90 feet from the mine mouth. In mining, only the lower 12 feet of coal is removed, the upper part of the bed serving as a roof that requires no support. The coal is brought to the surface by means of a small car on a steel track. The surface equipment consists of wagon scales, a substantial coal bin, and a dwelling house for the use of the miners. During the winter of 1910–11 about 450 tons of coal was sold at the mine at $1.50 a ton. The total amount of coal removed is probably not less than 2,000 short tons. A sample (laboratory No. 12627) was taken from the lower 12 feet of the bed at the back end of the entry. This analysis shows that the coal on the air-dried basis yields 13,000 British thermal units.

OTHER DRIFTS.

In the NW. ¼ NE. ¼ sec. 33, T. 22 S., R. 6 E., on the north side of Dipping Vat Creek, a tributary of Quitchuppah Creek, there is an abandoned drift on coal bed I. The total thickness of the coal could not be measured on account of caving and the presence of water. The drift is 20 to 30 feet long and the coal apparently equals in quality and thickness that exposed in the Browning mine. The strata dip more steeply at this place than at the Browning mine. It is estimated that at least 200 tons of coal has been removed.

A prospect drift (location 16, Pl. X) on coal bed A, in the SW. ¼ SE. ¼ sec. 33, T. 22 S., R. 6 E., on the north side of Quitchuppah Creek, bears nearly north and is about 50 feet long. Probably not more than 30 or 40 tons of coal has been taken from this prospect.

On the east side of Quitchuppah Creek, in the NE. ¼ NE. ¼ sec. 4, T. 23 S., R. 6 E., 75 or 100 feet above the stream level, another prospect, probably on coal bed A, was noted but not visited by the writer. There is also a small surface prospect on coal bed I (location 87, Pl. X) in the NE. ¼ NW. ¼ sec. 19, T. 22 S., R. 7 E. A small prospect drift, about 15 feet long, in the SW. ¼ NW. ¼ sec. 3, T. 26 S., R. 4 E., at location 409, exposes 6 feet 4 inches of coal in two beds. The entry is about 3 feet 8 inches in width and averages 4 feet in height, except at the back end, where a hole has been dug exposing the lower bed, of which the lower 3-foot bench of coal was sampled and is represented by laboratory No. 15090.

Coal has been mined at several places in the Emery field from surface exposures, but the total production of coal from the field probably does not exceed 6,000 short tons.

TRANSPORTATION ROUTES.

Two railroad routes have been surveyed into this coal field, one from the west and the other from the northeast. The former is considered to be the best by the company that controls the greater amount of coal land in this area, which is in the vicinity of Ivie and Quitchuppah creeks. Already about 20 miles of railroad, which is now in poor condition owing to floods, has been constructed eastward up Salina Canyon from Salina, which is on the Denver & Rio Grande Railroad. The additional construction of about 30 miles of railroad with a comparatively low grade would connect the heart of the coal field with the eastern terminus of the Salina Canyon branch. Such a route would furnish a more direct outlet to the Pacific coast than the route surveyed to the northeast through Castle Valley, joining the main line of the Denver & Rio Grande Railroad at Price or Wellington, and, in addition, would be equally direct to the Salt Lake City region. If the northeastern route is chosen, about 70 miles of railroad must be built over a country that presents practically as great difficulties mile for mile as must be surmounted on the western route, where only 30 miles is required. The Castle Valley Railroad has constructed a spur from Price as far southwest as Mohrland, in T. 16 S., R. 8 E., but only a small portion of this road could be used to advantage, as it is situated mainly high in the foothills adjacent to the Wasatch Plateau.

TONNAGE.

A careful estimate was made of the coal in the Emery coal field. It is assumed in calculating the tonnage that each acre of land underlain by a coal bed 1 foot thick (1 acre-foot) contains 1,800 tons. In the table given below two columns of figures are shown. The one on the left gives the estimated tonnage; the one on the right shows approximately the amount of coal that can be recovered, on the assumption that only 1,000 tons of coal can be mined from each acre-foot. By careful mining, however, much more than this amount may be recovered.

Estimated quantity of coal in Emery coal field, Utah.

Township.	Total coal.	Recoverable coal.
	Short tons.	*Short tons.*
T. 21 S., R. 6 E	21,463,000	11,923,000
T. 21 S., R. 7 E	311,000	173,000
T. 22 S., R. 6 E	427,176,000	237,320,000
T. 22 S., R. 7 E	21,736,000	12,075,000
T. 23 S., R. 5 E	214,310,000	119,061,000
T. 23 S., R. 6 E	355,877,000	197,710,000
T. 24 S., R. 5 E	268,389,000	149,106,000
T. 24 S., R. 6 E	33,171,000	18,027,000
T. 25 S., R. 4 E	30,093,000	16,741,000
T. 25 S., R. 5 E	54,734,000	30,408,000
T. 26 S., R. 4 E	1,805,000	1,002,000
	1,429,065,000	793,546,000


R. 10 E.
R. 11 E.
R. 12 E.
T. 15 S.
Wellington
DENVER
RIO
GRANDE
Price
FAULT
FAULT
Cottonwood Wash
Mounds
Verde
Cr.
17

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DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Bulletin 629

NATURAL GAS RESOURCES OF PARTS OF NORTH TEXAS

GAS IN THE AREA NORTH AND WEST OF FORT WORTH

BY

EUGENE WESLEY SHAW

GAS PROSPECTS SOUTH AND SOUTHEAST OF DALLAS

BY

GEORGE CHARLTON MATSON

WITH NOTES ON THE GAS FIELDS OF CENTRAL AND SOUTHERN OKLAHOMA

BY

CARROLL H. WEGEMANN

Work done in cooperation with the cities of Dallas and Fort Worth

WASHINGTON
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CONTENTS.

ILLUSTRATIONS.

INTRODUCTION.

By David White, Chief Geologist.

The citizens of Dallas and Fort Worth, numbering about 210,000, owe their prosperity in no inconsiderable degree to the supply of natural gas which, during the last 6 years, has contributed materially to their household comfort and industrial advantage. Dallas and Fort Worth utilize, for heat and power, natural gas piped from the Petrolia gas field, near Red River, in northern Clay County, about 105 miles northwest of Fort Worth. The gas is brought to the city limits by a producing company and is distributed within the cities by local organizations.

Confronted by questions as to the sufficiency and the prospective duration of the gas reserves, in view of the rapid increase in gas consumption, the mayors and city governmental commissions of these cities, in order to promote the welfare of the citizens, began inquiries as to the extent of the present source of supply and as to the existence of other sources within reach of these cities. The information sought should be available for their guidance in determining just and reasonable rates to be fixed in future franchises. In accordance with this purpose, the United States Geological Survey was, on the initiative of Mayor Henry D. Lindsley and the city of Dallas, requested to investigate the gas resources of the region tributary to that city. Favorable consideration being given by the Director of the Geological Survey to the request for a service so distinctly public, a conference of the city officials and the chief geologist of the Survey was held at Dallas, September 7, 1915, in which Mayor E. T. Tyra and other representatives of the governing muncipal commission of Fort Worth participated.

At this conference it was arranged that the Geological Survey should make an investigation of the gas resources of the Petrolia field, in Clay County; of the Mexia field, in Limestone County, the utilization of which by these cities had been under local discussion; and of such other areas within reach of the two cities as might possibly contribute, on a successful commercial scale, to meet adequately the eventual demands for natural gas. The two cities jointly pledged the greater part of the cost of the field examinations, thus making

the investigation cooperative. The Survey undertook to investigate the resources of the gas fields mentioned and to examine the geologic structure, as far as it affects oil and gas, of so much of the area tributary to Dallas and Fort Worth as might be surveyed with the funds allotted and within the time available before January 1, 1916, when the conclusions of the geologists were to be communicated simultaneously to the mayors and to the public, according to the Survey's usage. Geologists G. C. Matson and E. W. Shaw were assigned to the investigation of the regions southeast and northwest, respectively, of Fort Worth, and within a few days after the conference geologic examinations were begun by Mr. Matson in the Mexia field and Mr. Shaw in the Petrolia field.

Besides the detailed studies of the geologic structure and gas resources of the two principal gas fields already discovered in the zone tributary to the cities, reconnaissances were made of several counties and local structural studies were made at a number of points where either gas had been reported or the surface indications or geologic structure were found, in the course of the reconnaissances, to be favorable to the occurrence of pools of oil or gas. Such local studies were made along Wichita River and near Henrietta, in Clay County; near Benbrook, in western Tarrant County; and both north and south of the Mexia-Groesbeck gas field, at Wortham, Currie. Mabank, and Cash, along the general trend of the axis of the anticline. The geographical relations of the regions studied in detail are shown on figure 1, which shows also the areas covered by previous reports.

After the return of Messrs. Matson and Shaw to Washington, in November, for the purpose of compiling their field data and preparing their reports, field examinations were continued by Heath M. Robinson, assisted by C. W. Hammen, in the vicinity of Strawn and Weatherford. At the same time a structural survey of the Corsicana field was made by O. B. Hopkins. Time is not available for the inclusion in the present report of the detailed description, with structure maps, of any of these areas, but a map and short description of the Strawn field are given.

Meanwhile, in order better to advise the cities as to the possibilities of augmenting the city supplies, if the need should arise, by gas drawn from the southern border zone of the east-central Oklahoma oil and gas region, the examinations of 1914 in the Loco and Duncan[1] gas pools were supplemented by brief field inspections and some local studies by C. H. Wegemann of the gas developments resulting from recent drilling south of Muskogee and westward to and beyond

[1] Wegemann, C. H., The Loco gas field: U. S. Geol. Survey Bull. 621, pp. 31–42, 1915. The Duncan gas field: U. S. Geol. Survey Bull. 621, pp. 43–50, 1915.

Ada. The importance of the developments, the distribution of the gas wells, the probable life of the wells, and the probabilities of further discoveries of gas in large quantities in this zone are discussed

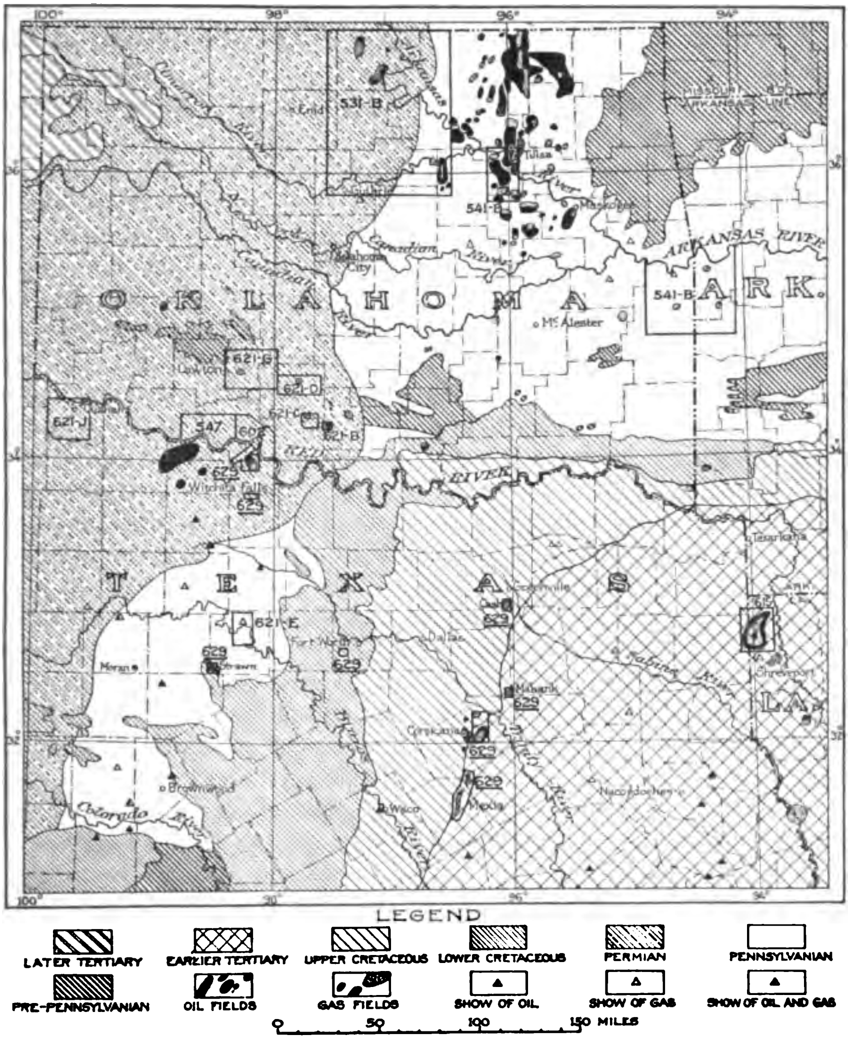


FIGURE 1.—Index map showing oil and gas fields and areal geology in parts of Texas, Oklahoma, Arkansas, and Louisiana. The rectangles marked with numbers indicate areas recently surveyed and the numbers of bulletins of the Geological Survey describing them.

in the notes by Mr. Wegemann. A detailed report by him covering parts of the area will be published later.

In undertaking this investigation, the Survey has endeavored to answer the following questions:

How much gas are the developed fields within reach of Dallas and Fort Worth capable of producing now?

How much gas remains in the developed pools and how long will this gas last, if marketed at an estimated rate?

Is it likely that the area of any or all of the fields will be increased?

Is it likely that new producing sands will be found in any of the fields?

What quantity of gas, within broad limits, is likely to become available through enlargement of existing fields?

Are new fields likely to be discovered; and if so, where?

The conclusions offered in reply to each of these questions represent the experience and judgment of the geologists in charge of the work and are based upon such local studies and information as could be gained within the time allotted. However, the answer to the last question, which is destined ultimately to become first in importance, is only partial, notwithstanding the efforts still in progress at the time of writing this report. If Petrolia be taken as marking the maximum distance (which it does not) within which natural gas can be regarded as tributary to Dallas, the area lying within that radius will include the whole of about 35 counties and the greater part of 6 or 7 others. The impossibility of covering all this area with detailed structural examinations under the conditions as to time and money controlling the present investigation is obvious. To cover even one-fourth of this region within a single year would require far more than all the funds which the Geological Survey has available for such investigations. Nevertheless, the fact is most regrettable; for it is highly probable, if not certain, that within this zone, especially within its western half, there will eventually be found pools of both gas and oil, some of which may possibly be as productive as the Petrolia and Corsicana fields. The value of such examinations and structural studies can not be questioned, for, though it must always be borne in mind that only the drill can determine with certainty the location of oil and gas pools, the geologist, by making structural surveys, can not only render invaluable aid in finding the pools but can also reduce, with still greater economic benefits, the losses incurred in drilling dry holes.

The Survey's examination of the gas resources contributory to Fort Worth and Dallas is purely geological, dealing exclusively with the structure of the areas, the amounts of gas already produced, the probable amounts still reserved in the old fields, and the probabilities of discovering new pools sufficient to maintain an adequate supply of gas for these cities for the next decade or more. Questions concerning drilling, field equipment, repairs, transportation, marketing, amortization, and like matters are left to the mining and other engi-

neers and the business experts, and so also is the serious question of the effect on supplies and prices that may be caused by the competition of Wichita Falls, Waco, Dennison, Gainesville, Sherman, and other cities that may, by reason of more favorable geographic position or by bidding higher, take to themselves a part of the reserve here counted as contributory to Dallas and Fort Worth.

Although the subject of this study touches a matter in which there is local conflict of views, if not of interests, the Survey is concerned only with the problem of ascertaining the adequacy of the gas resources, both developed and undeveloped, in the tributary region.

The thanks of the Survey are due to the gas companies and to all parties interested for cordial and generous submission of data for use in this investigation, which, so far as it assists in ascertaining the extent of the gas deposits already found or in discovering new oil or gas reserves, will be of value to all. In Dallas and Fort Worth and their immediate vicinity the city officials and also Hon. H. W. Sumners, State Senator Bowser, and R. H. Dearing & Sons contributed or put the geologists in touch with those who could contribute many data concerning wells and outcrops. Mr. J. W. Culbertson, of the Wichita Gas Co., in the northern area, was generous in furnishing information concerning the Petrolia field, and Mr. W. P. Gage, vice president and general manager of the Lone Star Gas Co., has courteously contributed not only logs of wells but records of pressures and production. Mr. H. L. Sturm, Oil Co., and many others assisted in collecting well logs and other Mr. L. R. Hammond, Messrs. Bean and Gohlke, of the Developers data. Special acknowledgment is due to Mr. W. E. Wrather, an authority on the geology of many counties in north Texas and long a student of oil and gas problems, who has rendered unstinted assistance in the study of the northwestern part of the area.

For assistance in the work in the southern half of the area examined the Survey, through Mr. Matson, is especially indebted to a large number of citizens who have in many ways given generous assistance and information. Among those to whom special acknowledgments are due are Hon. T. F. Smith, President Wilder, of the Little Giant Oil & Gas Co.; President Nussbaum and Superintendent Anderson, of the Mexia Oil & Gas Co.; Superintendent Faulkner and Local Manager Whitehill, of the Corsicana Petroleum Co.; Mr. F. G. Clapp, manager of the Associated Geological Engineers; Mr. N. E. Ritchie, manager of the Pleasants Gas Co.; and Messrs. Blake Smith, J. T. Leech, T. Bennett, and Robert Jones, of Mexia, Tex.; Mr. C. Y. Welles, of Tulsa, Okla.; and Mr. C. L. Witherspoon, of Corsicana, Tex.

In estimating the quantity of gas, not only in partly developed but in newly discovered fields, the geologists were guided by no precedents known to them, but each, independently of the other, devised the same method of computation. It now appears, however, that a similar method had been used by W. H. Hammen and F. H. Olyphant and had been described by Dorsey Hager.[1] Naturally any estimate of undeveloped territory must start with the study of the underground structure considered with reference to the occurrence of gas, oil, and salt water, and with the mapping, according to the best geologic information, of areas that are probably gas-producing. Starting with this primary basis, Messrs. Matson and Shaw independently worked out the plan of utilizing for the calculation of the extent of a gas pool the geologist's determinations of the average thickness of the gas-bearing sand, the average percentage of pore space in the sands, and the pressures of the gas in the rocks. The results attained are necessarily only approximate, and factors that affect them are discussed by Messrs. Matson and Shaw in their respective papers.

The detailed conclusions reached by the geologists, together with the discussion of the geologic and economic facts, will be found in their reports. Great credit is due to both geologists for the extent and value of the results they have accomplished under conditions that made the preparation of reports, within a period all too short, especially trying.

The answers to the questions as to the extent of the reserves of natural gas in north Texas, so far as they are answered in these reports, may be summarized as follows:

1. The Petrolia field, according to Mr. Shaw's calculations, is about 40 per cent exhausted and now contains 70 billion cubic feet of gas. Although the closed pressures of the wells have declined more than half in the producing area, the field can for a time furnish a much larger monthly and somewhat larger daily output than the maximum it has heretofore been called upon to furnish. Any increase of output, of course, will correspondingly shorten the life of the pool. Taking into account all the factors discussed by Mr. Shaw, the gas reserve in this field is sufficient to meet the normal demands of the cities for three to five years longer, though shortages in cold weather will probably be felt much sooner. After this period the supply, if divided among all the towns drawing on this field, is likely to prove insufficient in winter, even though the field is thoroughly drilled and pumped to the limit of its capacity.

2. The Mexia-Groesbeck gas field, which has been looked upon with the greatest interest as a possible source of supply for Dallas

[1] Hager, Dorsey, Natural gas—its occurrence and properties: Eng. and Min. Jour., vol. 100, No. 24, pp. 959–961, Dec. 11, 1915.

and Fort Worth, is stated, after a thorough and careful study by Mr. Matson, to have an open-flow capacity of 220 million cubic feet a day at the present time. Mr. Matson concludes that, after most unfortunate waste and coincident damage to this field, there remain 31 billion cubic feet of gas (equal in heating value to 43 billion cubic feet of Petrolia gas), of which over 95 per cent may probably be extracted before the closed pressure is reduced to 15 pounds per square inch. The stage of development and the gas pressure in this field are sufficient to supply Dallas and Fort Worth, in addition to the five towns, including Waco and Corsicana, to which gas is now taken from the area, and the quantity is probably sufficient to meet the total normal demand of all these cities for about 3 years provided means can be found to check the present waste, the exact length of period being dependent in turn on economy of marketing, prices, and rates of consumption. Therefore, the practicability of utilizing Mexia-Groesbeck gas in Dallas and Fort Worth is an engineering and economic problem in which the cost to the consumers may be affected by competition between cities.

3. The smaller gas pools of the region tributary to Fort Worth and Dallas, so far as they have been developed or explored, are individually insufficient to supply these cities for any considerable time. None appear to be comparable to the two principal fields already mentioned, but combined they are capable of furnishing a large though at present indeterminable accession. The practicability of assembling the output from these minor scattered fields and conducting it to the two large cities is mainly dependent on equipment costs and selling prices and remains for the consideration of the engineer. Some of these lesser pools lie much nearer than the Mexia-Groesbeck and the Petrolia fields to these cities. If the gas in the better of them can be conserved it will eventually find a profitable market.

4. Besides the scattered oil and gas seeps in the area and the favorable local structures discovered by the geologists in the relatively small portions of the tributary zone they were able to examine thoroughly during the time available, there are in this zone undoubtedly many other areas beneath which the geologic structure is favorable. Not all of these areas by any means will be productive, but some may include gas or oil pools as valuable as the Mexia-Groesbeck, the Corsicana, and the Petrolia. Some of the favorable structures will contain oil, others gas, but more will yield both oil and gas.

5. Near the southern border of the Oklahoma oil fields, according to preliminary examinations made by Mr. Wegemann, gas occurs in amounts sufficient to furnish a supply for Dallas and Forth Worth for a considerable period, though the number of years can not at present be closely calculated. Gas pools of magnitude, as well as many very highly productive scattered wells, have already been discovered,

and the progress of development is constantly increasing the amount of gas in sight, for which there appears to be no present market. Further, it is probable that gas deposits of commercial value will later be found at other points in this region. The utilization of this gas at the present time, in amounts large enough wholly to supply these cities, would probably require branch lines to rather distant pools, and these, together with a long carry to delivery—about twice the distance from Petrolia to Fort Worth—are important factors in the problem of present commercial practicability. It must, however, be borne in mind that, should the need arise, here is to be found a supply that, in spite of its remoteness, is geographically tributary to these cities and will probably be needed later by them unless meanwhile exploration is vigorously prosecuted and new pools thereby found in the nearer zone in Texas.

The cities of north Texas are fortunate in having within reach gas supplies so abundant as to add materially to the comfort and prosperity of their citizens and still more fortunate in their prospects of developing from time to time new supplies in regions relatively close at hand. Nevertheless it is a public duty that may not transgress the propriety of a geological report to urge that a lesson be learned from the history of other cities which have had like resources of natural gas, namely, the lesson of conserving and husbanding this so ephemeral gift of nature for the higher service of the household rather than spending it too freely in industrial promotion.

Too high praise can not be found for the wisdom and progressive spirit shown by the mayors and city commissions of Dallas and Fort Worth in arranging for this investigation of the gas resources tributary to their cities. The wisdom of their action is in contrast with the records of extravagance, waste, and ultimate disappointment of some cities which for a time have enjoyed a cheap natural gas supply. These investigations, provided by the Texas cities, may guide not only to the fullest and best use of the discovered resources, but also. in particular, to the probable discovery and development of new reserves which will bring benefits to the cities that will be realized more and more in years to come.

GAS IN THE AREA NORTH AND WEST OF FORT WORTH.

By E. W. Shaw.

GEOGRAPHY.

Location and general character of the area.—The area covered by this report on the gas resources north and northwest of Fort Worth, Tex., extends from Dallas, Fort Worth, Weatherford, and Strawn northward to Red River. The region is one of rolling prairie, brushy hills, and forests. Some parts, such as that at Montague, underlain by the thick Trinity sand, and that at Palo Pinto, underlain by hard limestone, are rough; other parts, such as the broad divides underlain by shale in Clay County, are nearly flat. The general altitude ranges from 500 or 600 feet near Dallas to 1,400 or 1,500 feet near Palo Pinto, and the highest hills nearly reach 2,000 feet.

In the two months available for the field work most of the area was at least briefly inspected and certain districts were surveyed in detail. The districts to which most attention was given were those which the information in hand or that obtained by the inspection showed to be worthy of immediate attention. Further geologic study may show that other areas are more promising or important than any of these except perhaps the Petrolia field, which is the greatest gas field thus far developed in Texas. Plane-table surveys were made of several areas where outcrops are good in the hope of finding structural features (anticlines and domes) favorable to the accumulation of gas. One of these areas forms a belt along the south side of Wichita River between Red River, east of Byers, and Wichita Falls. Another is in the vicinity of Henrietta.

Supplies and markets.—The commercial geography pertaining to natural gas in the area examined concerns principally the relation of the developed oil and gas fields to markets. The region under discussion lies near the middle of the west side of the great south-central oil and gas region of the United States. The oil and gas fields of Oklahoma lie to the northeast, and beyond them are the gas fields of southeastern Kansas. A hundred and fifty miles east of Dallas are the Caddo, De Soto, and Red River oil and gas fields, and to the southeast and the south are the scattered Gulf coast fields of Louisiana

and Texas. Dallas and Fort Worth, which have a combined population of over 200,000, are the largest cities close to the area examined and constitute the largest market for gas. Also, the areas described in this report and the accompanying report by Mr. Matson are the nearest proved or probable gas regions to these cities, and the ones to which they naturally look first for supplies. Other gas-bearing areas are, however, within reach of Dallas and Fort Worth, the most productive being the gas fields of Oklahoma and those in the vicinity of Shreveport, La., though it is doubtful whether the supply of gas near Shreveport is sufficient to warrant the investment necessary for its transportation so far.

AREAL GEOLOGY AND STRATIGRAPHY.

As indicated in figure 1, the geologic formations outcropping in most of this region belong to the Carboniferous and Cretaceous systems. These systems are made up of several series and formations, each of which has its own peculiar kinds and associations of fossils—the remains and imprints of plants and animals that lived at the time it was laid down—by which, as well as by certain other characteristics, it may be recognized. The Carboniferous system, so called because it is the source of a large part of the world's output of coal, is made up of three parts known as the Mississippian, Pennsylvanian, and Permian series. The lowest of these series, the Mississippian, is not exposed in the region examined and has not been reached in many wells. The Pennsylvanian series, next higher, consists mostly of sandstone, bluish shale, thin limestones, and coal beds. It is buried under the Cretaceous along Red River, but it outcrops farther south, beginning near Bowie, and the area immediately underlain by it extends southwestward for 150 miles to Colorado River, gradually becoming wider. All the rocks seen in the vicinity of Mineral Wells, Eastland, and other towns south and southwest of Bowie belong to this series.

The Permian series crops out in an extensive belt that lies just west of the Pennsylvanian area. The principal differences between the Permian and the Pennsylvanian series are that the Permian rocks include little coal and consist largely of red shale. This series is widely known as the "Red Beds," for in most of the areas of its occurrence throughout the world it embraces great amounts of red shale and sandstone. The Permian and the underlying Pennsylvanian have yielded a large part of the oil and gas produced in northern Texas and practically all that is produced in Oklahoma and Kansas. Beds of both these series are also great oil and gas producers in West Virginia, where the Permian contains much less red rock. The Mississippian also yields a great deal of gas and oil in Pennsylvania, Illinois, and other States, and the Carboniferous

system is thus the most prolific source of fuels in the United States and probably the most prolific in the world.

Along Red River the lower part of the Permian contains very little limestone or gypsum; the middle part, which outcrops in the vicinity of Electra and Vernon, includes several thin beds of limestone and very little gypsum; and the upper part in areas farther west contains much gypsum. The proportion of limestone in the Permian rocks increases toward the south.

The Cretaceous system contains the oil and gas pools south of Dallas. This and the overlying Tertiary system are the principal sources of gas and oil on the Gulf coast, in California, in Wyoming, and in Colorado, and of coal in the Rocky Mountain States.

The Cretaceous system is made up largely of rather persistent and thick beds of whitish limestone, bluish shale, and poorly consolidated sandstone. Some beds of the limestone, such as those at Weatherford, are so fossiliferous as to be generally called shell rock, and still others, such as those at Benbrook, are hard and brittle. The Cretaceous sandstones consist of little but grains of quartz and are open and porous. Several are sources of water. The Cretaceous rocks contain gas at Corsicana, Mexia, and elsewhere, as is stated by Mr. Matson in his part of this report. The succession of rocks is shown by the following well log:

Log of well at Southern Methodist University, 4 miles northeast of Dallas, Tex.

[See Pl. VII, p. 78.]

	Thickness.	Depth.
Cretaceous system:		
Austin chalk:	*Feet.*	*Feet.*
Soil	6	6
White rock	159	165
Eagle Ford clay:		
Shale	10	175
Limestone	2	177
Shale	44	221
Limestone	6	227
Shale	23	250
Limestone	4	254
Shale	91	345
Limestone	3	348
Shale	10	358
Shale and bowlders	50	408
Gumbo	65	473
Blue shale and bowlders	55	528
Gumbo and bowlders	32	560
Shale and limestone bowlders	49	609
Gumbo and blue shale	63	672
Woodbine sand:		
"First Woodbine sand"	21	693
Limestone, hard	9	702
"Second Woodbine sand"	18	720
Shale	9	729
"Third Woodbine sand" and limestone bowlders	12	741
Gumbo	10	751
Limestone	15	766
"Fourth Woodbine sand"	18	784
Shale and water sand	16	800
Gumbo	15	815
Sand	12	827
Shale	21	848

Log of well at Southern Methodist University—Continued.

	Thickness.	Depth.
Cretaceous system—Continued.		
Woodbine sand—Continued.	*Feet.*	*Feet.*
"Fifth Woodbine sand"	32	890
Shale	18	898
Limestone shell	4	902
Shale	33	935
Broken limestone and "sixth Woodbine sand"	12	947
White rock and water sand	42	989
"Seventh Woodbine sand"	9	998
Washita group:		
Shale	32	1,030
Gumbo	14	1,044
Limestone	14	1,058
Gumbo	5	1,063
White rock	29	1,092
Limestone	22	1,114
"First Weatherford limestone"	25	1,139
Limestone	11	1,150
Gumbo	22	1,172
Limestone	7	1,179
"Second Weatherford limestone," hard	15	1,194
"Third Weatherford limestone"	11	1,205
Limestone	10	1,215
Gumbo and bowlders	22	1,237
Gumbo	16	1,253
Limestone	7	1,260
Gumbo	4	1,264
Limestone, soft	6	1,270
Limestone, hard	4	1,274
Gumbo	8	1,282
Limestone, hard	27	1,309
"Fourth Weatherford limestone"	39	1,348
(Reamed and set 10½-inch casing.)		
"Fifth Weatherford limestone"	30	1,378
Fredericksburg group:		
Goodland limestone:		
Limestone, hard	36	1,414
Limestone	8	1,422
Gumbo	4	1,426
Limestone	2	1,428
Limestone, hard	30	1,458
"Sixth Weatherford limestone"	10	1,468
Shale	5	1,473
Gumbo and bowlders	15	1,488
Gumbo	4	1,492
Hard limestone	20	1,512
"Seventh Weatherford limestone"	30	1,542
Limestone	16	1,558
Shale	6	1,564
Limestone, hard	8	1,572
Trinity group:		
Paluxy sand:		
??	48	1,620
"First Paluxy water sand"	19	1,639
Limestone	2	1,641
"Second Paluxy water sand"	15	1,656
Gumbo	4	1,660
Water sand	9	1,669
Gumbo	8	1,677
Gumbo, hard	11	1,688
"Third Paluxy water sand"	5	1,693
Water sand	14	1,707
"Fourth Paluxy water sand"	23	1,730
Iron pyrite and sand	12	1,742
Water sand	15	1,757
"Fifth Paluxy water sand"	2	1,759
Water sand	3	1,764
Hard sand	5	1,769
Gumbo	3	1,772
Glen Rose limestone:		
Limestone	14	1,786
(Set 8-inch casing.)		
Limestone	20	1,806
Gumbo	10	1,816
Limestone	30	1,846
Gumbo	7	1,853
Limestone	17	1,870
Limestone and shale	8	1,878
Limestone	9	1,887
Gumbo	6	1,893
Limestone	5	1,898
Sand	10	1,908
Shale and limestone bowlders	14	1,922
Limestone	8	1,930

Log of well at Southern Methodist University—Continued.

	Thickness.	Depth.
Cretaceous system—Continued.		
Trinity group—Continued.		
Glen Rose limestone—Continued.	*Feet.*	*Feet.*
Sand rock	6	1,936
Limestone and shale	9	1,945
Limestone	16	1,961
Limestone, hard	9	1,970
Limestone	22	1,992
Limestone, hard	40	2,032
??	47	2,079
Limestone, hard	19	2,098
??	15	2,113
Limestone	2	2,115
Gumbo	6	2,121
Limestone	6	2,127
??	9	2,136
Limestone, hard	12	2,148
??	12	2,160
Limestone	47	2,207
??	8	2,215
Limestone, soft	5	2,220
Limestone	5	2,225
Limestone, hard	10	2,235
??	7	2,242
Limestone	8	2,250
Travis Peak sand:		
??	46	2,296
Water sand	14	2,310
"First Glen Rose water sand"	6	2,316
Sand	8	2,324
Water sand	18	2,342
??	5	2,347
"Second Glen Rose water sand"	9	2,356
Carboniferous system:		
Pennsylvanian series (?):		
Red gumbo	5	2,361
??	339	2,700

Paluxy water bad; Travis Peak good.

GENERAL STRUCTURE.

The Cretaceous rocks dip rather steeply eastward (see fig. 2), so that the Trinity sand at the base of the system, which comes to the surface at Weatherford and Montague, lies more than 2,000 feet below the surface at Dallas and Sherman and still deeper farther east. On the other hand, the Carboniferous beds that outcrop at Henrietta, Palo Pinto, and elsewhere dip westward, though not so abruptly as the Cretaceous beds dip eastward, and in the western part of the State lie several thousand feet below the surface. Whether or not the Carboniferous rocks dip to the west in the eastern part of this region also, where they are deeply buried under the Cretaceous rocks, is not certainly known, and it is not certain even that they are present beneath Dallas. Perhaps along the eastern border of the region, under Sherman and Rockwall, where they lie several thousand feet below the surface, they dip to the east, so that their general structure in the State is that of a broad anticline or upwarp. In any case the Cretaceous rocks have a general terrace or broad anticlinal structure, for although their dip is so steep in the northeastern quarter of Texas that they all outcrop and their horizon is above the surface west of Bowie and Weatherford, they come down again, as it were, farther west, in the western part of the State. If the strata had no terrace or broad anticlinal structure the beds near the base of the Cretaceous, which

outcrop around Fort Worth, would in the western part of the State be many thousand feet above the present surface, but they occur at the surface. It therefore appears probable that the oil and gas in Wichita and Clay counties and in the area extending southward to Eastland occur along the edge of a great structural terrace.

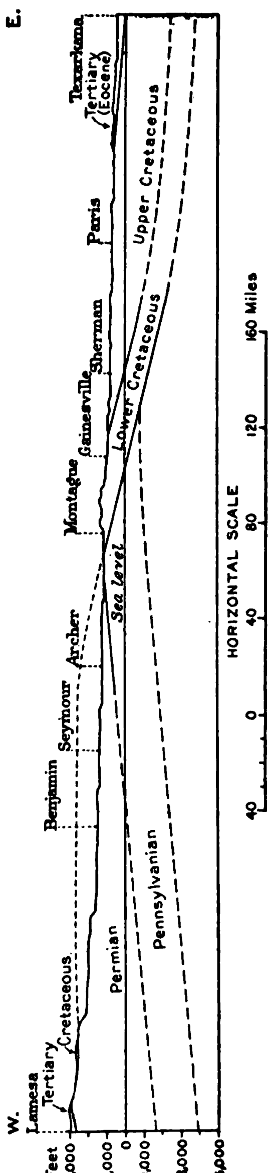


FIGURE 2.—Section across Texas along divide south of Red River from the eastern border of the State at Texarkana to Benjamin and thence southwestward to Lamesa, showing overlap of Cretaceous on Carboniferous formations and general terrace form of structure.

The general terrace form of the structure is not evident except to one who takes a broad view of the region, for the terrace is low compared with its breadth, and the layers of rock are more or less uneven throughout the region and at some places are uplifted into well-developed domes and anticlines. The local dips are nowhere much greater than the general dip and at few if any places exceed 5°. Here and there the rocks have been faulted.

The geology of the Cretaceous part of Texas has been described by Hill.[1]

CONDITIONS OF OCCURRENCE OF NATURAL GAS.

In most of the natural-gas pools of the country the gas is stored under pressure in the pores of sands or sandstones that lie more than 1,000 feet below the surface. Some gas has been found at depths greater than 3,000 feet, and some in other kinds of cavities. The pores of the gas-containing sandstone are commonly less than one-tenth of a millimeter—about $\frac{1}{250}$ of an inch—in diameter, yet the gas flows from them into wells at the rate of millions of cubic feet a day. Most of the pools are found in rocks which have comparatively large communicating pores and which lie near other rocks that contain much carbonaceous matter from which the gas may have been derived.

[1] Hill, R. T., Geography and geology of the Black and Grand prairies, Texas: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 7, 1901.

THEORIES OF ORIGIN AND ACCUMULATION OF NATURAL GAS.

The mode of origin of natural gas has never been clearly determined. It has not been possible to prove conclusively that it is either of organic or of inorganic origin, though most investigators agree that the evidence seems to indicate that both gas and oil were once parts of living organisms, and that they have been derived by a long process of distillation from the remains of plants or animals, or both, which have been buried in great bodies of sediment. The remains of plants seem to be a more likely source than the remains of animals. The grounds for these inferences are: (1) Although the hydrocarbons constituting petroleum and gas can be made from certain inorganic materials, such materials are not known to occur in the earth in considerable quantity, and if the gas and oil had been formed from such materials or if they had been original parts of the earth they must have migrated far from their sources, for the pools do not occur in deep-seated rocks but are closely confined in sedimentary strata, thousands of feet thick, which did not form an original part of the earth; (2) any hydrocarbon found in petroleum can be made in the laboratory from either plant or animal matter; (3) carbonaceous remains of plants are abundant in the strata in which oil occurs—more abundant probably than such remains of animals, for plants decay less readily—and fossil plants are generally carbonaceous, whereas animal fossils are rarely so.

Many things remain to be learned regarding the migration and accumulation of gas, but the inference—drawn very early in the history of the oil industry—that most oil and gas is stored in anticlines or upwarps of strata has been well demonstrated, the reason for their position being that they are lighter than water, so that under the water pressures that exist in the earth they tend to migrate to the highest spot attainable.

The exact nature and details of the process by which the gas migrates to the top of the anticline are still under discussion, the most important question being whether or not the salt water that at most places, if not everywhere, surrounds the pools must move and push the oil and gas about to a greater or less extent in order that the gas and oil may reach the top of the anticline. M. J. Munn[1] has argued with much force that such movement of water is necessary. The rock pores are so small that the friction would seem to be too great for the gas to migrate and segregate itself into extensive pools without the help of lateral movements of the water, which would favor this sorting by weight.

[1] Munn, M. J., The anticlinal and hydraulic theories of oil and gas accumulation: Econ. Geology, vol. 4, No. 6, pp. 509–529, 1909.

THE SEARCH FOR GAS.

Natural gas has not been so extensively and vigorously sought as oil, for only in regions in which it is abundant and which are thickly populated or not too far from large towns or industrial centers can it be marketed with profit. Many if not most natural-gas pools have been found in the course of the search for petroleum.

The first knowledge of oil in most regions seems to have been gained either from oil or gas seepages or by accident in drilling for water or coal. Of most pools, however, there were no surface indications before drilling began. The history of oil and gas "wildcatting" is in large part one of blind or even misguided waste, such as might be disastrous were not the gains from the occasional and frequently merely accidental successes so great. It is becoming more and more clearly recognized that in most oil regions of the world oil and gas pools occur in connection with dome, anticlinal, or terrace structures in the strata containing the oil and gas. Usually the gas occupies the upper part or crest of the fold. Accordingly, in his search for new pools or fields, the prospector should first examine the structure. Where anticlines are wanting or poorly developed, the geologic structure map may still be useful, for the strata nowhere lie perfectly flat, and it is everywhere possible to select certain structural features that are more promising than others.

Though the favorable forms of structure, even in oil and gas bearing formations, do not invariably contain pools, the places in which that structure is found are more likely than others to contain gas or oil. The principal unsolved problem concerns the exact places in which the rocks have favorable structure.

The field work requisite to a comprehensive and reliable statement concerning the gas resources available on the north and northwest to Dallas and Fort Worth consisted of—

First, a careful geologic survey of the Petrolia field, which is the present source of gas used by Dallas and Fort Worth. This work included the running of spirit-level lines to every well in the field, a careful study of the outcropping rocks in and near the pools, and the collection of logs of wells and a large amount of other data concerning them. Special attention was given to the details of the structure of the field, the thickness, number, and nature of the sands, and the gas pressures and yields.

Second, a similar though less elaborate and detailed study of other fields having gas wells within reach of the cities.

Third, plane-table stadia surveys of outcropping strata in several districts, made in the hope that structure favorable to the accumulation of gas might be found.

The ordinary method of search for gas pools is almost the same as that for oil pools, the most essential feature of it being the search

for anticlines. In Pennsylvania and West Virginia the anticlines nearest the Appalachian Mountains contain the most gas. Gas is generally more abundant in high, sharply defined anticlines than in low, broader structures, which commonly yield much oil. However, the criteria for locating gas pools, as distinct from oil pools, are not yet sufficiently developed to serve as a reliable guide. As all the rocks of the region under discussion may contain oil and gas, the search for new gas pools within reach of Dallas and Fort Worth consisted in hunting for anticlines and other favorable features of structure, especially in places where the underground water conditions appear favorable. The higher folds of the region are more likely to contain gas, but whether any particular fold will be found to contain oil or gas, or neither, can not be certainly foretold.

METHODS OF ESTIMATING GAS RESOURCES.

The estimation of gas resources, though very important, is comparatively new and undeveloped work. Many unknown quantities are involved in the estimates, and great precision in results will doubtless never be attainable. When gas properties change hands there must, of course, be some kind of an estimate of the amount and value of the gas still in the earth. The prices of some gas wells have been determined by the appearance of the well when it was opened. Generally, however, a measure of the closed pressure and a more or less careful estimate of the capacity is made. The common method of determining the capacity is as follows: The well is opened and allowed to blow off freely for 3 to 24 hours. Then a Pitot tube or spring gage is used in measuring the forward or momentum pressure of flowing gas. The opening of a pipe connected with the gage is turned against the stream of gas. The pressure is measured by a column of water or mercury or a spring gage, according to the force of the gas. The pressure reading is then expressed in cubic feet per day by means of a set of tables, the barometric pressure, the temperature, the specific gravity of the gas, and the size of pipe being taken into account.

In determining a proper price for the gas which underlies a farm or group of farms, the acreage of the land and the number of wells are also taken into consideration. These operations, which are applicable to discovered or partly developed fields, involve a large element of chance, but the estimation of gas resources in undiscovered fields is of course far more difficult, so difficult, indeed, that most oil and gas operators regard it as impracticable, and until wells are drilled one tract is regarded as about as valuable as any other that lies at the same distance from a producing field. Nevertheless, estimates vastly better and more reliable may be obtained for such tracts if careful consideration is given to the geologic structure and the

general relations of gas to structure in the same region. In the study of the structure attention should also be given to the number, thickness, and porosity of sands and the nature and arrangement of sands that bear salt water. These criteria have been borne in mind in estimating the gas resources about Dallas and Fort Worth. The fact that the Petrolia field is on a high, well-developed anticline may mean that smaller and less sharply defined anticlines in the same region are less likely to contain gas.

METHOD OF MAPPING STRUCTURE.

The problem of representing on a map the precise form of an uneven surface has been solved by the use of contours.

In structure contouring the surface of some bed is chosen and lines are drawn through points of equal altitude on that surface. The result shows the lay of the bed, just as a contour map of the earth's surface shows the lay of the land—that is, the form of hills and valleys, the direction and steepness of slopes, and the altitude of all parts of the surface. Features are shown in greater or less detail, according to the number of contours used and the number and precision of the determinations of altitude.

The method used in making the structure maps included in this report consisted in first looking over a group of outcrops in order to select a bed easily followed and then determining by plane-table and telescopic alidade the course of the outcrop and the altitude of points along it at intervals of a few hundred feet. Often, to afford a check on the results, a second or third bed above or below was traversed at the same time, for in making a structure map the geological surveyor is not limited to one bed, because all beds are nearly parallel and hence the wrinkles on one are generally at the same place and of the same form as those on another. Hence, here and there one bed was dropped and another picked up. Now and then, because of poor outcrops, a tract was altogether passed over, and where such gaps were great a barometer was used for carrying the level line in order to make more rapid progress. As a result the figures shown along outcrops on maps do not show precise altitudes above sea level, but are fairly precise with reference to each other.

In some places valuable inferences concerning structure could be drawn from the surface features. Some long, gentle slopes are immediately underlain by a hard stratum, and the surface thus indicates with greater or less certainty the direction and amount of dip. Elsewhere hard beds make little benches in hillsides, so that even where they are not exposed they may be followed, and in many places a concealed bed may be followed by fragments of the rock in the soil.

The accuracy and reliability of structure contours depend on several factors. In most of the surveys made for this report it was felt that the greatest danger of error was that of mistake in correlation—of following one bed or horizon for a while and then inadvertently shifting to another. This danger is due to the fact that, particularly in Clay County, the beds pinch out and change in character at short intervals. It was necessary to exercise the greatest care to avoid mistakes of this kind, particularly in correlating outcrops separated by short gaps, correlation across long gaps being generally quite impossible. As a result both outcrop lines and contours on the map are commonly represented by dashes, which indicate doubt as to exact position.

The beds are not only discontinuous but their surfaces are not sharply defined, and hence some of the altitudes determined are a little above and some a little below the surface that was followed. No doubt slight errors of this sort affect most of the points determined, but probably few such errors are in excess of 2 or 3 feet. They are not cumulative and hence do not affect the general structural features as shown on the map. Their effect is partly eliminated in drawing the structure contours, and thus the contours shown on the maps do not harmonize in detail with the determined altitudes.

THE PETROLIA GAS AND OIL FIELD.

LOCATION AND EXTENT.

The Petrolia field (see Pl. I) is on a broad, flattish divide between Wichita and Little Wichita rivers, just south of the town of Petrolia, in the northern part of Clay County, Tex. It has often been called the Henrietta field, because at the time it was discovered Henrietta, 12 or 15 miles to the south, was the nearest town. But the town of Petrolia has since grown up on the border of the field and this name is now more appropriate. It covers a somewhat elliptical area about 3 miles from northeast to southwest by 4 miles from southeast to northwest. The limits of the proved field can not be stated with precision, because some dry holes are nearly surrounded by productive wells and one or two productive gas wells are considerably outside of the main field, but an approximate boundary of the developed part of the field is shown on Plate I (in pocket).

STRATA ENCOUNTERED IN DRILLING.

The rocks outcropping in the Petrolia field and a large surrounding territory are widely known as the "Red Beds" and belong to the Wichita formation of the Permian series. They consist of lenticular beds of red shale, soft cross-bedded sandstone, and some blue-gray shale. Their fossils are rare and consist mostly of impressions and

remains of plants. The sandstone contains occasional fossil tree trunks and carbonized wood, which is here and there replaced by copper minerals, mainly malachite. There appears to be no limestone near Petrolia, though thin beds of limestone are fairly common in the higher parts of the Wichita formation exposed at Electra and in all parts of the formation at places farther south. Gypsum has been reported in some wells, but, though much gypsum occurs in the Wichita formation 50 to 100 miles to the west, it is doubtful whether any occurs in it in the Petrolia field, for no fragments were found in drill cuttings or slush pits.

The strata penetrated by wells in the Petrolia field, as shown in the following well logs, include several sands that produce oil or gas or both. On the whole, the quantity of gas increases with increase in depth. The sands that lie 150 to 300 feet below the surface contain very little gas, and probably for this reason the oil wells that derive oil from these sands have a low daily production and long life. Practically all the gas marketed comes from a group of sands that lie at a depth of 1,500 to 1,750 feet. This group is made up of three principal and two or three subordinate and lenticular sands.

Driller's log of Wichita Gas Co.'s well, on Felix Webb tract, No. 39, Chilson Neville & Kelley Subdivision, Block No. 13, Clay County, Tex.

[Contractor, M. D. Rowe. Drilled December 29, 1913, to February 5, 1914. Initial production (estimated), 10 million cubic feet of gas. Casing: 10 inch, 54 feet; 6 inch, 1,532 feet set with beveled shoe and cemented on top of sand. Six-inch Darling gate anchored to 10-inch casing.]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	131	131
Sand	6	137
Shale	50	187
Sand, showing oil	4	191
Gumbo clay	14	205
Shale and thin sandstone	73	278
Sand	47	325
Shale, soft	27	352
Sand, showing oil	8	360
Shale	25	385
Sand rock	35	420
Shale	11	431
Sand rock	11	442
Blue mud	15	457
Sand rock	34	491
Mud	5	496
Shale	7	503
Gumbo	15	518
Lime	6	524
Shale	10	534
Do	10	544
Gumbo	11	555
Shale	10	565
Do	21	586
Shale and shells	87	673
Sandstone, hard	7	680
Mud	27	707
Sand rock	8	715
Gumbo	5	720
Sand rock	8	728
Gumbo	17	745
Streaks of sand, showing oil	57	802
Mud	16	818
Gumbo	22	840
Sand rock	21	861

Driller's log of Wichita Gas Co.'s well—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale and thin sandstone	55	916
Sand rock	10	926
"Slate" and shells	29	955
Limestone	3	958
"Slate" and shells	24	982
Sand rock, hard	5	987
Gumbo and rock	19	1,006
Shale and sand	40	1,046
Mud	36	1,082
Gumbo and sand	36	1,118
Sand and shale	28	1,146
Sand, limestone, and shale	34	1,180
Rock	6	1,186
Sand rock	10	1,196
Gumbo and gypsum	124	1,320
Sand rock, showing water	12	1,332
Gypsum	22	1,354
Sand rock	6	1,360
Gumbo and bowlders	36	1,396
Gumbo, gypsum, and bowlders	88	1,484
Lime	5	1,489
Gypsum and streaks of sand	43	1,532
Sand, showing gas	6	1,538
Shale, blue	15	1,553
Sand, showing gas	14	1,567
Gumbo, tough	24	1,591
Sand, with black streaks, showing gas	10	1,601

Partial driller's log of Wichita Oil & Gas Co. well No. 5 on Culbertson tract, near middle of SW. ¼ block 14, Petrolia gas field, Texas.

[Drilled by Howell, Markowitz & Kell, April 19 to Sept. 2, 1914. Casing 10 inch, 60 feet; 6 inch, 1,545 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
??	1,000	1,000
Sand and bowlders, blue, soft	25	1,025
Gumbo, blue, soft	15	1,040
Gravel, red, soft	10	1,050
Sand rock, gray, hard	5	1,055
Gumbo, blue, tough	20	1,075
Gypsum, white, tough	4	1,079
Shale, blue, soft	21	1,100
Shale, sandy, blue, hard	50	1,150
Water sand, gray, hard	12	1,162
Water sand, gray, soft	200	1,362
Shale, blue, soft	113	1,475
Gumbo, blue, tough	20	1 495
Water sand, gray, hard	13	1 508
Shale, blue, soft	9	1,517
Gumbo, blue, tough	3	1,520
Gas sand, brown, soft	8	1,528
Gumbo, blue, tough	12	1,540
Shale, blue, soft	5	1,545
Gas sand, brown, soft	12	1,557
Gas sand, broken shale, brown and blue, soft	11	1,568
Gas sand, rich brown, hard	11	1,579
Gumbo, blue, tough	5	1,584
Gas sand, broken, and "slate," brown and blue, soft	10	1,594
Gas sand, brown, hard	16	1,610
Gumbo, blue streaks, tough	7	1,617
Cap rock, blue, hard	3	1,620
Gas sand, brown, soft	8	1,628
Lime or granite, red and white, hard	9	1,637
Limestone, brown, oil stain, soft	2	1,639
Limestone, white, hard	5	1,644
Gumbo, blue, tough	21	1,665
Lime, broken, white, hard	5	1,670
Limestone, white and brown, hard	75	1,745
Limestone, white, very hard	19	1,764

Driller's log of Developers Oil Co.'s well No. 12, near middle of NE. ¼ block 9, about 1 mile southwest of Petrolia.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay	10	10
Rock	2	12
Hardpan	20	32
Red clay	8	40
Sandstone, soft	3	43
Shale	45	88
Sand, hard	7	95
Gravel and clay	30	125
Shale, soft	70	195
Sand, oil	3	198
Sand, hard	7	205
Shale, soft	200	405
Clay, blue	40	445
Sand rock	35	480
Sand	3	483
Clay	80	563
Clay and rock	6	569
Sand	82	651
Sand rock	15	666
Gumbo	20	686
Oil sand	4	690
Sand rock	6	696
Shale	35	731
Oil sand	3	734
Sand rock	2	736
"Pack sand"	10	746
Shale	60	806
Clay	15	821
Sand rock	32	853
Clay	8	861
Sand rock	20	881
Shale	25	906
Sand rock	12	918
Sand, salt water	34	952
Clay	8	960
Sand rock	9	969
Shale	11	980
Do	15	995
Oil sand	7	1,002
Clay, blue	18	1,020
Shale, soft	20	1,040
Sandstone	17	1,057
Shale	10	1,067
Sand rock	8	1,075
Shale	30	1,105
Shale and clay	15	1,120
Sand rock	16	1,136
Do	27	1,163
Shells and clay	24	1,187
Shale	8	1,195
Sand rock	9	1,204
Clay, blue	18	1,222
Clay	15	1,237
Rock	6	1,243
Shale	20	1,263
Sandstone	6	1,269
Gumbo	5	1,274
Sandstone	10	1,284
Sand rock	2	1,286
Shale	10	1,296
Sand rock	8	1,304
Clay	20	1,324
Shale	20	1,344
Broken rock	16	1,360
Sand rock	(?)	(?)
Sand	(?)	1,395
Clay, blue	30	1,425
Shale	65	1,490
Sand rock	5	1,495
Sand	3	1,498
Clay	12	1,510
Sandy shale	42	1,552
Sand rock	15	1,567
Sand	5	1,572
Rock	3	1,575
Shale	6	1,581
Sand rock	3	1,584
Shale	18	1,602
Sand rock	8	1,610

Driller's log of Developers Oil Co.'s well No. 12—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale	12	1,622
Sand, hard	3	1,625
Clay	17	1,642
Clay, blue	20	1,662
Clay	15	1,677
Shale	20	1,697
Do	15	1,712
Sand, hard	15	1,727
Sand	30	1,757
Shale	6	1,763
Sand (set and cemented, 6-inch casing)	1	1,764
Sand—good gas	2	1,766
Sand, oil spray	7	1,773
Bottom sand	8	1,781
Shale	4	1,785
Sand	3	1,788
Blue mud (bottom of well)	2	1,790

Well completed May 27, 1914. Estimated capacity 12,000,000 cubic feet of gas. Shut in to save gas. Probably good for 5 to 10 barrels of oil.

On account of the high gas pressure and rather large yield of the main gas sands, few wells have been sunk to a greater depth within the proved field. The underlying strata include several layers of sandstone that are inclosed between comparatively impervious beds and that have pore space adapted to make them good oil and gas reservoirs. These deeper sands have been penetrated in wells outside the producing field, as shown in the logs on pages 66–68.

The main gas sands at Petrolia are believed by Prof. Udden[1] to belong in the Cisco formation, which is the uppermost formation of the Pennsylvanian series in this region. On account of the scarcity of fossils, however, it is not yet possible to define with certainty the boundary between this and the lower formations. The importance of carefully preserving shells and other fossils found in drilling is not sufficiently understood by the driller. Gordon's section of the rocks below the Wichita formation is as follows.[2]

Section of Pennsylvanian formations in Wichita region, Texas.

	Feet.
Cisco formation (clay, shale, conglomerate, sandstone, and some limestone and coal)	800
Canyon formation (alternating beds of limestone and clay; some sandstone and conglomerate)	800
Strawn formation (alternating beds of sandstone and clay; some conglomerate and shale; the lower 1,000 feet consists of blue and black clay locally containing beds of limestone, sandstone, or sandy shale, and a coal seam at the top)	1,900
	3,500

[1] Udden, J. A., and Phillips, D. McN., A reconnaissance report on the geology of the oil and gas fields of Wichita and Clay counties, Tex.: Texas Univ. Bull. 246, 1912.

[2] Gordon, C. H., Geology and underground waters of the Wichita region, north-central Texas: U. S. Geol. Survey Water-Supply Paper 317, p. 14, 1913.

STRUCTURE.

As pointed out by Udden and Phillips,[1] the structure of the rocks in the Petrolia gas field is anticlinal. The additional work done by the writer has only served to bring to light further details concerning the structure of the field and the surrounding territory. The more complete structural survey of the field has had the advantages afforded by the records of additional wells combined with plane-table surveys of outcropping rocks on all sides of the field, but especially along the river bluffs that extend from a point a few miles east of Byers west-southwestward nearly to Wichita Falls. These additional data bring out the fact that the oil and gas pools occupy the crest of a large, irregular anticline having a general east-northeast trend. The most important structural features in and near the Petrolia field identified by the present survey consist of a branch anticline extending a mile or two northeast of the middle of the field and a similar structure extending northwest. The form of these features is shown on the structural map. The fold to the northeast was discovered by H. M. Robinson from outcropping beds, and he determined its form so far as possible by a plane-table survey.

PRODUCTION.

The Petrolia field produces both oil and gas, and in recent years its production has increased rather rapidly. It is now yielding about 500,000 barrels of oil a year. Its production in 1912 was less than 200,000 barrels, and for several years before it had been nearly 100,000 barrels. The total amount of oil produced up to the close of 1914 is a little over 2,000,000 barrels, or about 11,200,000 cubic feet.

The annual production of natural gas consumed in Texas amounts to more than 10,000,000,000 cubic feet, and the Petrolia field is by far the largest producer. The production of the State in 1914 amounted to about 13,433,639,000 cubic feet, valued at $2,469,770.

HISTORY.

The first gas well in the Petrolia field was drilled in 1907. For several years before that date it was known as an oil field. The first shipments of oil were made in 1904, though it had produced small amounts of oil for several years before. The oil was first found in water wells, where it and the associated salt water spoiled many wells as producers of drinking water.

During 1904 about 75 oil wells were drilled. The average depth was about 300 feet, and their production ranged from 3 to 40 barrels a day. The oil had a paraffin base and was similar in character

[1] Udden, J. A., and Phillips, D. McN., A reconnaissance report on the geology of the oil and gas fields of Wichita and Clay counties, Tex.: Texas Univ. Bull. 246, 1912.

to that produced at Corsicana, to which place it was shipped for refining. During this year two pipe lines were laid to Petrolia, where loading racks were erected. An analysis of the oil, made at this time,[1] shows naphtha, 9.1 per cent; water-white oil, 54.5 per cent; solar oil, 13.6 per cent; heavy residues, water, and loss, 22.8 per cent.

In 1905, 52 additional wells were drilled, bringing the total number of producing wells up to 135. All were shallow, averaging only about 300 feet in depth. The cost of drilling was low, and 10 to 30 of the wells were operated by one power. During this year over 66,000 barrels of oil were shipped to refineries, nearly 10,000 barrels were used in boilers in the field, and about 26,000 barrels were put in storage. At about this time a large part of the field was "townsited" and offered for sale in small lots, the owners and promoters evidently believing that more money was to be made in this way than by drilling and producing. As a result, much of the field is now cut up into small blocks most of which have changed hands one or more times, a condition that greatly complicates the record of well locations.

By the close of 1907 there were 169 producing oil wells, all of them shallow, and the oil was being piped from the field by the Navarro Refining Co., successor to the Clayco Oil & Pipe Line Co. In October of that year the first gas well was brought in by this company. It was 1,500 feet deep and is reported to have had a 4-minute pressure of 470 pounds to the square inch, and a capacity of 8 to 10 million cubic feet a day. In 1908 two other "gassers" were brought in, the gas being used for domestic purposes in Petrolia as well as for operating boilers and for other purposes in the field.

In 1909 several other gas wells were drilled and the 16-inch pipe line to Fort Worth and Dallas was laid. From this date the number of gas wells has gradually increased until now about 56 produce gas, all of them deep wells. In addition, a smaller but steadily increasing number of deep oil wells have been drilled. Many wells yield little or no salt water, but on the whole the proportion of salt water in both gas and oil wells is increasing, as it commonly does in oil fields. Some of the deep wells yield both gas and oil in proportions that show a wide range, the proportion of oil showing a slight general tendency to increase.

Many of the first deep wells in the field showed closed pressures of more than 700 pounds to the square inch, the highest pressure reported being 740 pounds. The average pressure has gradually decreased and now is less than half as great as at first. (See Pl. II.) Very naturally the capacity of the wells has also fallen off considerably, and on account of the decline in pressure and volume a large

[1] U. S. Geol. Survey Mineral Resources, 1904, p. 715, 1905.

compressor plant furnishing a pressure of about 300 pounds to t
square inch has been built by the Lone Star Gas Co., the principal
producer in the field. When the pipe line was installed and for t
following two or three years the pressure and volume of the w
were great enough to maintain this 300-pound flow pressure, wh
was necessary to force the gas to Fort Worth and Dallas in suffici
quantity to meet the demand. In fact, at first the requisite amo
could be delivered at the cities by using only a few wells and allow
them to flow into the pipe line for only a part of the time, but si
then the consumption has greatly increased and the capacity a
pressure of the wells has decreased, so that the installation of
compressor plant was necessary. A large pipe line or additional p
lines would have made it possible to furnish the requisite amount
gas for a year or two longer without compression, but the build
of the compressor plant could not have been long postponed.

EFFECT OF METHOD OF DRILLING ON DISCOVERY AND PRODUCTION.

The wells of the Petrolia field are bored to the supposedly prod
tive sands by rotary drills, but as the mud used with these drills m
so mask the sands as to obscure to a greater or less extent their ca
bilities for producing oil or gas and may even totally conceal rich
and gas sands, it is the common practice to drill the sands with ca
tools. These tools are installed after the hole has been sunk with
rotary drill nearly to the top of the sand which is expected to
productive.

Drilling is done in a way more favorable to the development of
wells than of gas wells, on account of the fact that an oil well is wo
in general much more than a gas well. The attempt is thus genera
made to make an oil well if possible. When a gas sand is found t
operator attempts to drill through it, in the hope of finding oil
paying quantities beneath the gas. Thus it happens that much g
has been allowed to go to waste, and many gas wells have be
"killed," because they were considered not worth caring for. O
operators commonly have an arrangement with a gas company to s
to it all gas wells as fast as drilled, so when the attempt to make
well an oil well fails on account of the abundance and high pressu
of gas, the well is turned over to the gas company. The gas compa
commonly finds it convenient to give a purchased well a new numb
or designation, and this practice leads to confusion in names of wel

After it is finished each well has its own history, which differs mo
or less from that of any other, not only in geologic but in technolog
detail. Some wells are short lived and others maintain a large yie
for many years. Some become bridged over or are in other wa
troublesome; others require very little care.

GAS RESOURCES.

Distribution of gas wells.—As shown by the map (Pl. I), the gas wells, about 56 in number, are fairly evenly distributed throughout the Petrolia field. Very few unsuccessful deep wells have been drilled within the field. Many that are called oil wells are in fact capable of producing considerable gas also, the general practice being, as noted above, to make as many oil wells as possible. In the northwest corner of the field in particular efforts to this end have been very successful. Here, especially in blocks 9 and 13, the gas sands of the central part of the field contain a great deal of oil. Though most of the wells here produce gas, in only a few does gas preponderate to such an extent as to cause them to be rigged up as gas wells.

The limits of the Petrolia gas field are generally considered to be pretty well determined by the drilling so far done. Most of the deep wells within a fairly well defined boundary (see line on Pl. I) are productive, and those outside are nonproductive, though the Morgan Jones No. 1, of the Ninety-nine Pumping Co., is a notable exception. This well has not so large a capacity as most wells in the field, but though it is more than a mile west of the nearest gas well in the field, it is a very good gas well.

Depth of wells.—Most wells over 1,000 feet deep yield more or less gas, and the big gas wells range in depth from 1,500 to 1,750 feet. Contrary to a prevalent opinion, the sands do not lie almost perfectly horizontal but have dips which in a few miles cause considerable differences in their altitude. The dips are much less than the general slope of the surface of the region, though they are sufficient to carry the beds down or up scores of feet within a mile.

Closed pressure and capacity of wells.—The initial closed pressure of the first few gas wells drilled in the Petrolia field ranged from 600 to 740 pounds to the square inch. Since these wells were drilled their closed pressures have not only decreased but the initial pressures of other wells drilled later have been lower than that of earlier wells, some of the latest wells drilled having recorded initial pressures of less than 300 pounds to the square inch. The initial pressure depends in part on the stage of development of the field and in part on the surrounding producing wells—whether they are numerous or few, distant or near by, old or recently drilled, or have been much or little used. The following table, showing the rate of decrease of closed pressure as ascertained by monthly gaging of most of the gas wells in the field, is compiled from records kindly furnished by the Lone Star Gas Co. These monthly gagings were begun in January, 1913, and have been continued to date.

Rock pressures of gas wells at Petrolia, Tex., belonging to Lone Star Gas Co., 1913–1915.

[Figures show line pressure at well mouth, in pounds to the square inch.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1913.												
Byers 1	a 725	a 730	a 730	a 725	a 595	—	—	—	—	—	—	—
Byers 4	a 710	a 710	a 710	a 715	a 715	a 665	a 660	a 670	a 675	a 665	a 665	a 670
Byers 5	a 640	a 650	a 640	a 630	a 630	a 360	a 560	a 555	a 550	a 220	490	a 475
Byers 6	635	a 640	630	620	610	a 535	a 540	a 525	a 520	480	445	415
Byers 12	...	...	...	...	(335)	(315)	(330)	(325)	(325)	(345)	(375)	(315)
Byers 15	...	...	...	...	...	...	...	...	...	a 470	a 445	a 390
Holt 1	a 615	a 615	a 615	a 615	a 630	a 570	a 560	a 560	a 550	445	480	530
Matlock 1	a 565	a 560	a 565	a 565	a 585	430	425	a 485	440	435	420	475
Landrum 1	a 635	a 640	a 640	a 655	a 650	a 590	a 590	a 585	a 585	a 575	a 545	a 575
Schnell 1	a 720	710	a 710	a 705	a 720	a 655	a 650	645	655	a 665	665	a 660
Schnell 2	a 570	530	a 560	a 560	a 565	a 505	a 495	a 500	a 490	a 495	a 450	a 435
Brick & Tile 1	485	—	—	—	—	—	—	—	—	—	—	—
Brick & Tile 2	520	505	435	505	510	430	440	435	445	480	445	460
Miller 1	580	570	560	555	560	540	525	460	455	430	455	425
Smith Webber 1	520	a 530	a 560	a 555	a 560	a 505	a 500	a 510	a 505	a 510	430	420
Smith Avis 1	a 655	a 650	a 655	a 660	a 650	a 615	a 610	a 645	a 620	a 625	a 615	a 605
Lockridge 1	a 660	a 655	a 655	a 665	a 685	a 635	a 625	a 635	a 640	a 635	a 630	a 615
Panhandle 1	595	a 595	a 590	a 590	a 585	a 580	a 570	540	525	515	505	490
Clayco Stine 1	645	a 650	a 650	a 660	a 670	a 610	a 605	a 610	a 615	a 650	a 630	a 615
Holloway 2	(315)	(310)	(310)	(275)	(290)	(295)	(315)	(315)	(315)	(315)	(315)	a 410
Holloway 4	a 615	a 615	a 635	a 640	a 620	a 590	a 590	575	510	515	—	—
Taylor 2	(325)	(320)	(325)	(285)	(300)	(315)	(325)	(325)	—	—	—	—
Skelly 1	a 675	a 590	a 590	a 585	a 595	a 565	510	a 530	a 430	a 525	a 515	480
Skelly 4	...	...	...	...	...	...	...	...	...	...	...	475
C. P. Stine 1	...	...	...	a 605	a 565	a 355	a 365	—	—	—	—	—
Skelly 2	650	585	590	(415)	(420)	(395)	(410)	300	—	—	(ab)	...
Total number wells	22	22	22	23	24	24	24	24	24	25	24	25
Total number off test	2	3	3	4	5	6	5	6	7	7	7	6
Total number tested	20	19	19	19	19	18	19	18	17	18	17	19
Average per well	621	617	622	621	615	540	538	553	541	518	519	506

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1914.												
Byers 1	—	—	—	—	—	—	—	—	—	...	—	—
Byers 4	655	670	625	560	575	...	515	505	500	...	465	510
Byers 5	440	410	375	342	345	...	340	340	340	...	300	305
Byers 6	(365)	370	325	307	300	...	295	305	a 300	...	300	240
Byers 12	(325)	—	290	—	—	...	—	a 185	a 180	...	200	140
Byers 15	350	350	310	—	—	...	280	a 275	a 265	...	240	230
Byers 17	...	...	...	...	...	...	270	a 255	a 285	...	250	230
Byers 19	...	...	...	610	555	...	510	490	495	...	—	505
Byers 20	...	...	...	...	...	...	575	550	575	...	500	520
Holt 1	510	505	460	450	440	...	400	405	395	...	350	350
Matlock 1	440	435	420	375	360	...	340	325	335	...	310	350
Landrum 1	555	510	450	420	395	...	420	420	380	...	320	365
Schnell 1	680	675	635	630	590	...	540	525	600	...	—	—
Schnell 2	480	480	435	425	425	...	395	385	390	...	355	350
Brick & Tile 1	—	—	—	—	—	...	350	335	335	...	335	290
Brick & Tile 2	425	415	385	360	390	...	330	320	335	...	310	250
Miller 1	(350)	—	—	—	—	...	—	—	—	...	—	—
Smith Webber 1	475	450	400	400	390	...	360	350	355	...	315	305
Smith Avis 1	585	555	507	487	480	...	450	450	460	...	420	415
Lockridge 1	595	480	425	375	360	...	275	265	250	...	360	365
Panhandle 1	470	460	425	400	400	...	375	375	355	...	310	310
Clayco Stine 1	585	570	530	507	507	...	480	470	420	...	420	440
Holloway 2	475	480	420	(280)	465	...	280	425	375	...	355	b 505
Holloway 4	—	—	—	—	—	...	—	405	420	...	365	355
Taylor 2	—	—	—	—	—	...	—	—	—	...	—	—
Skelly 1	—	455	415	—	400	...	—	—	360	...	320	315
Skelly 4	465	465	420	405	400	...	370	365	360	...	335	325
C. P. Stine 1	—	—	—	—	—	...	—	—	—	...	420	—
Brotherton 1	...	...	...	...	...	...	...	...	...	...	320	315
Holmes 1	...	...	...	...	...	...	...	...	...	...	...	320
Total number wells	25	25	25	25	26	...	28	28	28	...	29	30
Total number off test	9	7	6	8	8	...	7	5	4	...	5	5
Total number tested	16	18	19	17	18	...	21	23	24	...	24	25
Average per well	511	485	434	431	432	...	388	379	377	...	341	344

a Wells not in use.
b Closed 16 hours before test.

Figures in parentheses are estimates, the wells being impossible to shut in for test.
A dash (——) indicates that well was in bad order and no test was made.
Totals do not include records in parentheses.

Rock pressures of gas wells at Petrolia, Tex.—Continued.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1915.												
Byers 1	—	—	—	—	—	—	—	—	—	—	—	......
Byers 4	485	425	435	480	455	465	455	450	440	435	430	......
Byers 5	245	280	265	240	240	240	240	240	230	225	225	......
Byers 6	195	185	175	155	150	185	175	170	160	155	130	......
Byers 12	175	150	130	135	100	100	55	—	—	—	—	......
Byers 15	180	165	145	145	145	150	140	130	110	120	110	......
Byers 17	175	160	115	140	135	135	65	—	—	—	—	......
Byers 19	465	475	465	455	435	435	420	410	400	390	385	......
Byers 20	530	530	475	455	445	445	430	420	400	345	335	......
Holt 1	360	355	350	330	320	325	325	320	305	300	300	......
Matlock 1	310	345	335	335	320	320	330	335	320	315	315	......
Landrum 1	355	350	345	325	335	325	325	310	295	310	300	......
Schnell 1	—	—	—	—	—	—	—	—	—	—	—	......
Schnell 2	355	345	335	335	315	325	310	320	310	310	310	......
Brick & Tile 1	295	265	275	285	250	310	285	260	235	240	255	......
Brick & Tile 2	240	235	210	205	185	265	290	300	295	290	290	......
Miller 1	320	300	305	305	300	300	285	300	300	300	300	......
Smith Webber 1	295	290	300	290	280	280	295	285	290	285	285	......
Smith Avis 1	405	415	410	415	390	395	395	390	385	375	370	......
Lockridge 1	—	—	—	—	—	395	400	390	370	355	335	......
Panhandle 1	315	325	320	310	305	300	310	305	295	295	280	......
Clayco Stine 1	425	445	425	435	420	420	415	410	400	385	370	......
Holloway 2	410	460	420	340	440	350	455	470	460	265	290	......
Holloway 4	345	345	335	335	335	335	335	335	330	320	315	......
Taylor 2	......	......	Disconnected.		......	......	......	......	......	......	......	......
Skelly 1	310	315	300	310	305	300	310	295	290	285	280	......
Skelly 4	315	315	315	315	295	295	300	295	280	295	290	......
C. P. Stine 1	—	—	—	—	—	—	—	—	—	—	—	......
Brotherton 1	250	280	255	285	290	255	200	160	150	135	155	......
Holmes 1	240	280	255	285	290	255	195	155	150	120	145	......
Culbertson 1	240	245	195	225	260	240	190	155	130	95	—	......
Hammond 1	350	350	340	325	320	320	325	320	300	305	305	......
Patterson 1	......	......	305	290	285	290	290	280	260	265	265	......
Beatty 1	......	......	440	420	400	400	395	360	350	330	320	......
Minnick 1	......	......	......	—	—	—	—	—	—	—	—	......
Landrum 2	......	......	Not in use.		......	[a] 325	325	320	305	310	300	......
Smith Webber 2	......	......	......	......	......	......	200	180	—	—	150	......
Brotherton 2	......	......	......	......	......	......	Plugged; mudded up.			......	......	......
O. G. Stine 1	......	......	......	......	......	......	......	......	175	175	165	......
Myers 1	......	......	......	......	......	......	......	......	215	205	205	......
Total number wells	32	31	33	34	34	35	37	37	39	39	39	......
Total number off test	5	4	4	5	5	4	5	7	8	8	8	......
Total number tested	27	27	29	29	29	31	32	30	31	31	31	......
Average per well	318	320	309	307	302	306	296	302	288	275	274½	......

[a] Wells not in use.

The average closed pressure of these wells is shown diagrammatically in Plate II.

The capacity of the wells—that is, the quantity of gas which they are capable of yielding per day—has not been so carefully measured as the closed pressure. The tests are more difficult to make and involve considerable loss of gas. The individual wells had an estimated initial capacity of 10,000,000 to 40,000,000 cubic feet of gas a day and a "settled" capacity of 5,000,000 to 35,000,000 cubic feet. Estimates as to settled production are unsatisfactory, not only because they are rarely based on careful tests but also because there is no such thing as a fixed settled production. The capacity decreases continuously, and though not so rapidly after a year or two as at first, the decline continues at a perceptible rate.

The facts that Dallas uses only about 12,000,000 cubic feet of gas a day and that the 50 wells of the Petrolia field are reported to have capacities of 10,000,000 to 40,000,000 cubic feet each may seem to the

casual reader incompatible with any suggestion of shortage. The fact is, however, that the capacities of the wells are not so great, and for various reasons it is not possible to market all or even a large part of the capacity of wells. The general conditions should be regarded by all as calling for taking good care of the supplies available.

Number, thickness, and extent of the sands.—Three principal and several subordinate sands, all more or less lenticular, yield gas in the Petrolia field, the three principal sands being more than 1,500 feet below the surface. As reported in the logs of wells, the average thickness of sand, exclusive of dry, oil, and water sands, is about 30 feet. However, many wells have not been sunk through all of the pay sands, and hence the average "pay" penetrated in the wells is only about 25 feet.

The volume of pay sand in the Petrolia field can not be determined with great precision, but a fairly accurate estimate may be made from the average total thickness of pay sands and the area of the field. If the boundary of the field be defined as shown on the map (Pl. I), so as to include the main mass of productive wells, its area is a little over 7½ square miles. This boundary, however, leaves out the "Ninety-nine" well, which is just outside the area mapped, and no doubt considerable areas underlain by gas-bearing sand. The full extent of the gas pool is probably about 15 square miles, an area indicated by the fact that the favorable structure extends beyond the borders of the field as now developed, by the relation between closed pressures and amount of gas produced, and by the application of the doctrine of chances to the percentage of successful wells about the margin of the present field. If 15 square miles be taken as a minimum and the average thickness of pay sand 30 feet, the total volume of pay sand is about 12,545,000,000 cubic feet.

Pore space of the sands.—Fragments of the producing gas sand large enough for tests of pore space are difficult to obtain, but a few fragments one-quarter to one-half inch and one 2 inches in diameter were procured. Some of these were tested by C. E. Van Orstrand and some by the writer and their pore space was found to range from 18.5 to 27 per cent. The results are not so satisfactory as they would have been if more and larger specimens had been available, but it is fairly safe to assume that the average pore space of the sand is at least 20 per cent and not more than 25 per cent. At 20 per cent the total volume of pore space occupied by gas in the known gas field would be about 2,509,000,000 cubic feet.

Original amount of gas.—The quantity of gas originally in the Petrolia field may be computed roughly from the total volume of pore space in the gas-bearing rock and the gas pressure at the time the first gas well was drilled. If the average original pressure was 725 pounds to the square inch the gas would have occupied a little more

than one-fiftieth of the space it would have occupied at 8-ounce pressure. If the area originally underlain by the gas were 15 square miles, the average thickness of pay sand 30 feet, the average pore space 20 per cent, and the pressure 725 pounds per square inch, the original quantity of gas would have been 120,432,000,000 cubic feet, which, if all recovered and used at an average rate of 10,000,000,000 cubic feet per year, would last 12 years. The production could not, of course, be kept up at this rate until the gas had been exhausted, so there would be a gradual decline in the production and the life of the pool would be somewhat longer.

Quantity of gas thus far produced.—The quantity of natural gas produced in Clay County from 1907, the year the first well was drilled, to 1915 is about 37,000,000,000 cubic feet. This figure is based on the statistics showing the quantity of gas marketed. An estimate based on the pressure gradient and the thickness, volume, and percentage of pore space of the sand gives, however, a considerably larger figure, and it seems that the field has been depleted by about 50,000,000,000 cubic feet, the difference being the wasted and other unmarketed gas.

Quantity of gas remaining.—Estimates of gas in the earth, based on pressure curves, depend for accuracy largely on the fact whether or not water follows up the gas in the sand as fast as the gas is removed. If the water does not follow up the gas in the sand then the difference in closed pressure from time to time should indicate rather accurately the amount of gas that has been removed, because if the volume of gas remains stationary Boyle's law demands that the quantity must decrease about as the pressure decreases.[1] If, however, as the pressure decreases water flows into the sand because it has access and is under great pressure, the closed pressure will not decrease so rapidly as the volume in the sand decreases on account of production. If a very large volume of water under the same pressure as the original gas pressure in the pool had free access to the sand, and if the gas were removed from a well in the middle of a pool, it is conceivable that water might follow up and keep the pressure practically as high as the initial pressure until the pool was exhausted. In the Petrolia field water has apparently followed up the gas to an appreciable though small extent so that the closed pressures are not a close index of the rate of depletion, but, on account of discontinuity of sands and consequent lack of free access of water, the pressures have no doubt fallen off nearly as rapidly as the volume

[1] R. F. Earhart and S. S. Wyer, in manuscript to be published by the American Society of Mechanical Engineers, state that Boyle's law is not closely applicable to natural gas. Samples of gas were found to expand more rapidly than the pressure decreases. Presumably this does not imply that Boyle's law needs revision, but it does imply a molecular rearrangement in some of the constituent gases; also, as has long been known, many gases do not expand precisely as pressure decreases, even though apparently no molecular rearrangement takes place.

has decreased. The basis for this inference is (1) that the pressures have fallen off in nearly the same proportion as the depletion of the field, as indicated by the statistics of production, probable waste, and computations of the original volume of pore space, and (2) the marginal wells have not yet shown a much greater tendency to "go to water" than wells in the middle of the fields. Of course, it is not to be expected that there should be a regular dropping out of wells from the margin toward the center of pools, because water may take the place of gas in a well in the middle of a field on account of unusually open sand about the well or because an unusual quantity of gas may be taken from the well, for water generally has access to the pay part of the gas sand from below as well as from the sides. Other factors also may prevail to keep a well productive or to render it unproductive notwithstanding its location.

An important factor in the length of life of any gas pool is the completeness of extraction which is possible. Because of irregularities in composition and structure of sand, obviously not every atom of gas can be taken from the sand, and many pools have been abandoned which may still contain a considerable quantity of gas. However, on account of the great original pressure and the consequent relatively small original volume of the gas, together with its elasticity, it is apparent that when the pressure in a well has been reduced nearly or quite to zero, the percentage of the original amount of gas remaining in the sand and having access to the well must be low.

Possibility of extension of field.—A most interesting question concerning any discovered gas or oil field is whether or not the producing area may be extended, either by discovering that the sands continue, under favorable structural relations, into neighboring areas, or by finding new sands in the areas that are already producing from other sands. The average of all opinions, estimates, and guesses is generally well reflected in the prices asked and given for property in and about the margins of the pool, and it is interesting to compare such opinions with those based on a geologic survey. Judging by real estate values the operators in the Petrolia field do not seem to expect any great extension. Land about the margin of the productive area is almost as cheap as land at some distance from it, and the prices of oil and gas land within the area seem to depend largely on the quantity of oil or gas now being produced. Indeed, it may be said that a gas well in the middle of the field will not bring a much higher price than the cost of drilling and equipping the well.

On the other hand, the results of geologic work indicate that the field is likely to spread laterally in one or two directions. The attitude of the rocks is favorable to an extension of the field a mile or two beyond the limits of the proved area both to the east-northeast

and to the west-northwest. A favorable structure in the area to the east-northeast is indicated by outcropping beds, the altitudes of which at many points were determined by H. M. Robinson. Contours based on these altitudes are shown in Plate I. The inferences formed concerning structure in the area to the west-northwest are based on well logs, which indicate that the contours open out in that direction. The outcrops in this area are not sufficient for satisfactory structural work, so the precise attitude of the rocks is not known, but there is good reason to expect an extension of the field in that direction.

The stratigraphy of the Permian and Pennsylvanian formations indicates that they include many beds of sandstone, which are pretty well distributed from top to bottom and many of which are adapted to form good oil and gas reservoirs. Below the bottom of the deepest well yet drilled in the Petrolia field there are several sands that may form good oil and gas reservoirs. This conclusion is further supported by the logs of the deepest wells drilled in surrounding territory. For example, in the well drilled to a depth of nearly 4,000 feet on the Halsell farm, near Henrietta, sands are reported at fairly short intervals to a depth of 2,400 feet, and occasional thin layers of sand are reported at greater depths. The well recently drilled a few miles southwest of Waurika, still nearer the Petrolia field, shows also numerous sands down to 2,000 feet, some of which would make good oil reservoirs were the structure and other conditions favorable. The log of the Halsell well, samples from which were studied by Professor Udden, is given in his report on this region and also in M. J. Munn's report on the Grandfield district, Oklahoma. The log of the lower part of the Waurika well is given below. One or more of these deeper sands may contain gas in paying quantities, despite the fact that one or two lower sands already penetrated in wells within the proved field are barren. One of these barren sands in particular is known to some drillers as the "Gulf of Mexico," because it yields immense quantities of salt water. The fact that its yield of salt water is so great may indicate that a short distance away there is a gas pool under great pressure which forces the water out of the sand and causes the wells tapping it to flow copiously.

The history of most gas fields justifies the inference that deeper productive sands may lie below sands now producing. This inference does not apply to some fields, such as certain Illinois oil fields, where the productive sand is underlain by formations that do not contain porous strata. In many apparently exhausted pools, however, deeper drilling has struck lower productive beds. The development of important though not great extensions of the producing areas in the sands now tested may therefore be expected, and also the finding of some gas in underlying sands not yet touched in the structurally higher parts of

the pool. Since as a general rule the deeper the gas sand the more the gas is compressed, any gas found below the sands now producing is likely to be under high pressure.

Probable life of the field.—By plotting the average closed pressure of all the wells of the field month by month in the form of a curve, the pressures being shown as abscissas and the time as ordinates, a formula may be deduced from which the probable life of the field may be estimated by extrapolation or by extending the curve according to the formula. An estimate of the length of life of the Petrolia field made in this way indicates that the closed pressure will reach zero in 5 or 10 years.

For practical purposes three additional facts must be taken into consideration. One, which has already been noted, is that the pressure curve is probably not declining quite so rapidly as the loss of supply, because water and oil follow up the gas to a certain extent and keep the pressure higher than it would otherwise be. The second is that when gas is under high pressure in the presence of oil a considerable quantity dissolves in the oil and is given off when the pressure is relieved, so that really the pool originally contained and still contains more gas than would be indicated by the pressure and the amount of pore space. The third is that some time before the pressure reaches zero it will become impracticable to market the gas unless some special device is used to make complete extraction possible, in which event the life of the field will be lengthened but the daily output greatly diminished.

The problem may be approached in still another way. Comparison may be made with other gas pools now abandoned which had similar areas, sands, pressures, and market demands. Of course every pool is to a certain extent unique, so the results of such a comparison can not be precise. The approximation has, however, much value, and if the length of life of the Petrolia field as now developed be estimated in this way, the conclusion is reached that the pool will last five or six years longer.

The above figures are independent of the probable extension of the field, both as to area and as to number of producing sands. When allowance is made for these facts the figures are increased by 40 to 50 per cent, and after making proper allowances and adjustments the author reaches the conclusion that the Petrolia field will produce gas from 8 to 12 years longer, but that several years before the end of this period the annual yield will begin to fall off, notwithstanding the fact that new wells will be brought in and that powerful pumps will be used to keep the production up, so that much sooner the cities of Dallas and Fort Worth will need to look to other fields for an adequate supply for even domestic use.

Quality of gas.—The chemical constitution and heating value of the gas in the Petrolia field are shown by the following typical analyses:

Analyses of three samples of gas from Petrolia field.

[Nos. 6751 and 6752 are from Wichita Falls Gas Co.'s No. 1 Matlock well, which supplies the town of Petrolia; the third sample (X) is from Beatty No. 1 well, and the figures were furnished by the Lone Star Gas Co. Bureau of Mines, Nov. 19, 1915; G. A. Burrell, analyst.]

	6751	6752	X
CO_2	Trace.	0.2	0.2
O_2	.0	.0	.0
CH_4	48.5	48.4	52.7
C_2H_6	12.8	12.8	9.3
N_2	38.7	38.6	37.8
Total	100.0	100.0	100.0

6751 and 6752. Specific gravity (air=1), 0.78; heating value per cubic foot at 0° C. and 760 millimeters pressure, 755 British thermal units.
X. Specific gravity (air=1), 0.76; heating value, 734 British thermal units.

The most striking and important characteristic is the high nitrogen content of the gas. On account of the large percentage of this inert element the heating value is only 755 British thermal units, or about the same as that of artificial coal gas, whereas the Mexia and many other natural gases show over 1,000 British thermal units. Another interesting character is the presence and quantity of the ethane (C_2H_6) reported by the Bureau of Mines—a gas that has a heating value of more than 1,700 British thermal units and a specific gravity nearly twice that of methane (CH_4). It has also a much greater illuminating value than methane. The ethane suggests a relation between the gas and associated oil and next to the nitrogen constitutes the most important point of difference between the Petrolia and the Mexia gas. The fact that it is possible to extract considerable gasoline from the gas, one small plant for this purpose being already in operation, suggests that the part reported as ethane includes other substances.

Numerous tests made by the city of Dallas seem to show an increase in heating value of the gas since the compressor plant was built at Petrolia, the rise being from about 750 British thermal units to about 800 British thermal units based on a freezing point temperature and 30 inches of atmospheric pressure.

OTHER KNOWN GAS FIELDS IN TEXAS NORTH AND WEST OF FORT WORTH.

ELECTRA-BURKBURNETT FIELD.

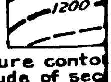
The oil-producing sands of the Electra-Burkburnett field are probably not a potential source of natural gas, though some wells in it have capacities of more than a million cubic feet, but it is possible that small pools of gas exist in deeper sands not yet penetrated. The

pertinent facts are that the structure in the Electra-Burkburnett field is favorable to the accumulation of both oil and gas, though more favorable to oil, that the formations are such as yield gas elsewhere, and that sands suitable for gas reservoirs have not yet been reached by the drill in many parts of the producing field, and some have not been reached anywhere within it. There is no reason to expect that the field will ever produce much gas, though it may produce enough to be worth piping to some nearby towns.

STRAWN OIL AND GAS FIELD.

The Strawn oil and gas pool lies just west of the town of Strawn, in the southwest corner of Palo Pinto County. The most thickly drilled portion of the field is about 2 miles west of the town, where most of the wells are oil wells. Most of the gas wells are 1 to 2 miles south of the main oil area, though there are some gas wells among the closely spaced oil wells. Other oil and gas wells are scattered over an area 2 or 3 miles from east to west and 9 miles from north to south, and among them are several dry holes. The field is only about a year and a half old, but about 100 wells, most of which are producing, have been drilled. Many of these wells are productive, and the output of oil is now said to be 400 or 500 barrels of oil a day. The combined capacity of the gas wells is probably about 50,000,000 cubic feet per day. Most of the wells are between 800 and 1,000 feet deep and have been drilled with Star machines. Gas was found some time before oil.

The rocks at Strawn belong to the Canyon and Strawn formations (Pennsylvanian), and the pool, like the one at Moran, though stratigraphically considerably lower, is in strata which are favorable to the formation and accumulation of both oil and gas. The beds are of the same age as others that contain oil and gas elsewhere, they are carbonaceous, they have numerous sands of varying porosity, and they have not been tilted about and disrupted until the oil, gas, and salt water have been washed out or allowed to escape. The structure, as determined by H. M. Robinson and C. W. Hammen, and shown in Plate III, is roughly that of a dome on a terrace and is favorable to the accumulation of oil and gas. The dome is, however, flat or low—much lower than that at Petrolia—and this fact, together with the well data, suggests that the volume of oil in the sands is greater than that of gas. The general dip is northwest about 70 feet to the mile. The field is little more than half as far from Fort Worth and Dallas as the Petrolia field and is a possible source of gas for those cities, but the present capacity of the field is not nearly great enough to warrant piping so far, and it is somewhat doubtful whether even if it were entirely drilled the field would furnish so great a quantity of gas as to warrant piping to Fort Worth.



Structure conto
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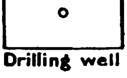


Drilling well

Logs of two wells showing the number, thickness, and distribution of the sands are given below.

Log of Palo Pinto Oil Co.'s well No. 5, on the Swenson farm, 2 miles west of Strawn, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay	10	10
Water, sand, and gravel	10	20
Shale, blue	50	70
Lime, hard	27	97
Shale, blue	113	210
Shale, hard, and bowlders	12	222
Shale, blue	38	260
Red rock	25	285
Shale, blue, and bowlders	285	570
Sand	5	575
Shale, blue	19	594
Sand	10	604
Shale, blue, and bowlders	161	765
Gas sand	5	770
Shale, blue	45½	815½
Sand, broken	22½	838
Hard water sand	1	839
Oil sand	4	843
Sand, blue	1	844

Log of Bendrum & Trees well No. 1, on Ackermann tract, in southwest corner of Palo Pinto County.

	Thickness.	Depth.
	Feet.	*Feet.*
Sandstone	44	44
Limestone, hard	41	85
Shale, blue	315	400
Red rock	15	415
Limestone, hard	9	424
Shale, blue	476	900
Limestone and sandstone	18	918
Shale, blue	27	945
Sand, hard, gray	19	964
Shale, blue	41	1,005
Sand, hard, show of oil	17	1,022
Limestone shell	8	1,030
Shale, blue	30	1,060
Limestone shell	6	1,066
Shale, blue	39	1,105
Limestone, blue	4	1,109
Shale, blue	56	1,165
Sand, close, show of oil	10	1,175
Sand and shale	7	1,182
Sand, hard, red, show of gas	6	1,188
Sand, water	37	1,225
Shale, blue	45	1,270
Shale, sandy	10	1,280
Shale, blue	25	1,305
Shale, sandy	69	1,374
Sand, water	9	1,383
Shale, blue	9	1,392
Sand, water	9	1,401
Limestone shell	3	1,404
Shale, blue	31	1,435
Shale, sandy	11	1,446

Some small faults have been observed near Strawn. In the Mount Marion mine a fault trending N. 75° W. and having a downthrow on the southwest side of 15 feet has been traced for 3,000 feet.

A generalized section of the rocks exposed in the Strawn field has been compiled by H. M. Robinson and is given below:

Generalized section of rocks exposed in Strawn oil and gas field, Texas.

	Feet.
Conglomerate, chert, and quartz pebbles, with siliceous cement; pebbles average one-fourth inch in diameter, fairly well rounded	1
Limestone, weathers gray; fresh surface shows numerous calcite veinlets; contains a bed of conglomerate 1 foot thick; makes top of Loyd Mountain	45
Shale, gray	10
Limestone, sandy; numerous crinoid stems and other fossils	5
Clay, bluish gray; numerous white streaks and blotches	5
Shale, sandy	5
Sandstone, buff, loosely cemented, irregularly bedded; cross-bedding common	15
Shale and clay, bluish gray	15
Sandstone and sandy shale; sandstone is buff and on the whole is irregularly bedded; cross-bedding common	55
Interval for most part grassed; presumably made up mostly of shale; some sandy shale and one or two limestones each about a foot thick	110
Limestone, resistant, exposures poor; estimated thickness	2
Shale and shaly sandstone; exposures poor	20
Sandstone, light brown, massive, thick bedded, grains medium size and fairly well rounded; weathers to dark rusty brown, massive, irregular blocks; generally closely cemented	3
Sandstone, brown, massive, loosely cemented in some portions; some portions very friable, slightly coarser grained than member immediately above. Grains mostly quartz. Pore space comparatively large in some parts of the member. In some places minute cross beds less than an inch thick are evident. Olive-colored specks as large as a small pea and imperfect cross bedding are common in lower part. Cross beds average about 1 foot in thickness	50
Sandstone very similar to that above but contains much more iron. Apparently because of irregularity in distribution of the cementing material, the sandstone weathers into very irregular shapes. In lower portion of member are some light-brown specks and streaks which are probably $FeCO_3$	10
Interval of grassy slope, more gentle than the upper concealed interval, probably friable sandstone, light gray	12
Limestone, very arenaceous. This member forms the top of the first terrace below top of the main ridge in the field. Light gray, weathering darker, fine-grained, fairly well cemented, weathered surface hard and smooth. This member contains a resistant ledge just above the fossil horizon, which is the key rock used for the structure map (see Pl. III)	10
Limestone, light gray, beds rather thin, averaging 1 to 2 inches. Highly fossiliferous. Abundant crinoid stems, Productus (?), and Bryozoa (?); breaks with an irregular fracture	12
Sandstone, cream-colored, very fine grained. Calcareous. Bedding fairly well developed; beds average about 4 inches thick; well cemented. Weathers darker in color	7
Shale, sandy at base and top, light buff	8

	Feet.
Sandstone, very calcareous; abundant crinoid stems; some as large as 1 inch in diameter and several inches long	1
Shale, sandy, and thin sandstone beds 2 inches to 1 foot thick; tan-colored in the main	60

The quality of the gas is shown by the following analyses:

Analyses of two samples of gas from Strawn oil and gas field.

[No. 6838 is from Stuart Bros.' well No. 10 (Texas Pacific Coal Co. No. 37), from pipe line one-fourth mile from well. No. 6839 is from Texas Pacific well No. 15, from pipe line 1 mile from well. Collector, H. M. Robinson. Bureau of Mines, Dec. 17, 1915. G. A. Burrell, analyst.]

	6838	6839
CO_2	0.00	0.00
O_2	.00	.00
CH_4	79.00	78.20
C_2H_6	13.90	12.90
N_2	7.10	8.90
	100.00	100.00
Specific gravity (air=1)	0.65	0.66
Heating value at 0° C. and 760 millimeters pressure per cubic foot	1,100	1,072

MORAN OIL AND GAS FIELD.

The Moran oil and gas field lies southeast of Albany, near the southeast corner of Shackelford County. The 40 or 50 producing wells are, as at Strawn, scattered over an area 2 or 3 miles across, and among them are occasional dry holes. Most of the oil wells are from 1 to 2 miles west of the town, and the gas wells, which are much less numerous, are to the east of the oil wells. The yields of the wells, even of wells that are close together, differ greatly. One 5-barrel well is only one location from a 600-barrel well, which is only two locations from a dry hole, and one location farther there is a well which at first yielded only a show of oil, then 25 barrels a day and a good showing of gas, and then went dry. Another well is reported to have made 3,000,000 cubic feet of gas for about four days and then to have changed abruptly to an oil-water well.

It has been known for years that the field contained natural gas in paying quantities, but active drilling did not begin until 1913. Exciting interest in the field began when the No. 1 Wild came in with a reported yield of 20 to 30 barrels of oil at the start and 40 to 50 barrels a little later. The No. 1 Edwards yields 100 to 200 barrels of light-gravity oil, reported to be 45° Baumé, from a depth of a little more than 2,500 feet.

The facts concerning the Moran field that are of principal interest to the people of Dallas and Fort Worth are that the geology of the district appears to be favorable to the existence of a valuable pool of oil and gas; that the rocks, except those near the surface, belong to

the Pennsylvanian series, which commonly contain much gas; that the beds are carbonaceous, as they commonly are in oil and gas regions; and that the sands are lenticular and have not been so disturbed as to cause the oil, gas, and salt water to be washed out of them.

The field is evidently capable of producing considerable gas, though the present indications are that its yield will not be great enough to pay for a pipe line to Fort Worth and Dallas, which are farther from it than from Petrolia. Several logs showing the approximate number and thickness of sands and other features of the stratigraphy in various parts of Shackelford County are given below:

Driller's log of well No. 1 on Terry farm, Shackelford County, Tex., southeast corner SW. ¼ block 47, Lunatic Asylum land.

[Drilled August 1 to December 5, 1912.]

	Thickness.	Depth.
	Feet.	*Feet.*
"Surface"	130	130
Shale, blue	50	180
Red mud	20	200
Limestone, gray	10	210
"Slate," white	40	250
Red mud	25	275
Limestone	10	285
Red mud	15	300
Shale, blue	25	325
Shale, dark	25	350
Red mud	30	380
Limestone	5	385
Red mud	15	400
Limestone	10	410
"Slate," white	40	450
Shale, red	20	470
Sand, gray	5	475
Limestone, blue	15	490
Limestone	10	500
Shale, red	5	505
Red rock	45	550
Shale, blue	25	575
Limestone, gray	10	585
"Slate," white	15	600
Limestone	5	605
Shale, dark	10	615
Shale, light	25	640
Limestone	5	645
Shale, white	15	660
Sand, blue	10	670
Red rock	5	675
Sand, show oil	2	677
"Slate," black	3	680
Limestone, gray	5	685
Red rock	10	695
Brown shells	5	700
Pink shells	25	725
Lime, gray	25	750
Shale, gray	50	800
Red rock	30	830
Sand, water	20	850
Shale, gray	120	970
Shale, brown	30	1,000
Shale, gray	80	1,080
Shale, brown	20	1,100
Shale, gray	40	1,140
Limestone, gray	10	1,150
Shale, gray	40	1,190
Sand, salt water	50	1,240
Shale, gray	5	1,245
Limestone, gray	5	1,250
Sand, gray	5	1,255

Driller's log of well No. 1 on Terry farm, Shackelford County, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
"Slate" and shells	95	1,350
Limestone, white	130	1,480
"Slate," black	50	1,530
Sandy limestone and water	5	1,535
Limestone, white	145	1,680
Limestone, blue	80	1,760
Limestone, white	20	1,780
Water	10	1,790
6-inch casing	5	1,795
Limestone, blue	10	1,805
Limestone, crystalline	25	1,830
"Slate"	10	1,840
Limestone, white	70	1,910
"Slate," white	90	2,000
Limestone, white	10	2,010
"Slate," blue	6	2,016
Sand, water	4	2,020
6-inch casing	25	2,045
Limestone, blue	25	2,070
Limestone, white	10	2,080
Limestone, black, water	65	2,145
"Slate," black	5	2,150
Limestone, white	60	2,210
"Slate," black	5	2,215
Sand, white	20	2,235
Sand, black	35	2,270
Sand	15	2,285
Show of oil at 2,280-2,285 feet.		
Sand, white	15	2,300
4½-inch casing set at 2,300 feet.		
"Slate," black	50	2,350
Limestone, white	10	2,360
"Slate," black	40	2,400
Limestone, white, shells	40	2,440
"Slate," black	10	2,450
Limestone, white	40	2,490
Limestone, white, gritty	25	2,515
Red shell and cave	5	2,520
Limestone, white	10	2,530
"Slate," black	5	2,535
Limestone, white	15	2,550
Shale, blue	80	2,630
Limestone, white	5	2,635
Shale, blue	110	2,745
Sand, dark gray, hard, no water	20	2,765
Shells	30	2,795
Limestone, white, gritty	....	2,705
Water filled up hole 500 feet.		

Log of Corsicana Petroleum Co.'s well No. 1 on the Weddington farm, in Shackelford County, Tex.

[Contractor, J. W. Dyson. Drilled April to August, 1912. Casing: 13 inch, 416 feet; 10 inch, 1,116 feet; 8 inch, 1,520 feet; 6 inch, 1,785 feet; 5 inch, 2,720 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Shale, red	30	30
Limestone	4	34
Shale, dark	40	74
Limestone	5	79
Shale, white	50	129
Shale, red	21	150
Limestone, soft	35	185
Shale, white	10	195
Lignite, black	5	200
"Slate," black	15	210
Sand (6 boilers of water)	35	255
"Slate," white	50	300
Limestone	5	305
Coal	5	310
"Slate," black	20	330
"Slate," white	10	340

Log of Corsicana Petroleum Co.'s well No. 1 on the Weddington farm in Shackelford County, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand	35	375
Shale, white	10	385
Sand, white	20	405
"Slate," white	5	410
Limestone	10	420
"Slate," white	40	460
Limestone	10	470
"Slate," black	80	550
Limestone	15	565
"Slate," white, and limestone	20	585
"Slate," black, and limestone	25	610
"Slate" and limestone	25	635
"Slate" and shell	80	715
Limestone, sandy	15	730
"Slate," black	40	770
Sand	15	785
"Slate," black	60	845
Limestone	6	851
"Slate," white	50	901
Limestone	9	910
"Slate," white	20	930
Red cave	15	945
"Slate" and limestone	110	1,055
Black cave	40	1,095
"Slate," white	10	1,105
Sand	12	1,117
"Slate," black	5	1,122
Sand and shale	28	1,150
Limestone	15	1,165
Shale, black	4	1,169
Limestone	160	1,329
Sand, white	60	1,389
"Slate" and shells	135	1,524
"Slate," white	10	1,534
Limestone	11	1,545
"Slate," black, and shells	80	1,625
Limestone, sandy	50	1,675
"Slate" and limestone shells	110	1,785
Shale, black	90	1,875
Limestone and slate	50	1,925
Shale, pink	55	1,980
Limestone	20	2,000
"Slate"	80	2,080
Limestone	80	2,160
Limestone, sandy	40	2,200
"Slate" and shells	425	2,625
Limestone, sandy	10	2,635
"Slate" and shell	40	2,675
Limestone, hard	8	2,683
"Slate"	12	2,695
Limestone, hard	5	2,700
"Slate," white	10	2,710
Sand, white	9	2,719
"Slate"	6	2,725
Limestone, black, hard	5	2,730
"Slate," black	35	2,765
Limestone, sandy	40	2,905
"Slate" and shell	80	2,985
"Slate"	49	3,034
Bottom dry.		

Log of Reynolds No. 1 well, 3 miles north and half a mile west of Albany, Shackelford County, Tex.

[Drilled from Sept. 23, 1913, to Mar. 22, 1914.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface	40	40
Limestone	12	52
Shale, white	13	65
Shale, pink	10	75
Shale, blue	20	95

Log of Reynolds No. 1 well, 3 miles north and half a mile west of Albany, Shackelford County, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Limestone and shells and white "slate"	85	180
Rock, red	45	225
Shale, blue	35	260
Shale, pink	10	270
Shale, blue	15	285
Shale, gray	135	420
Limestone	25	445
Shale, blue	10	455
Rock, red	12	467
Limestone shells	18	485
Shale, gray	40	525
Rock, red	15	540
Shale, white	20	560
Limestone	25	585
Shale, gray	5	590
Limestone	10	600
Shale, gray	25	625
Slate, black	10	635
Limestone	25	660
Slate, gray	35	695
Rock, red	20	715
Limestone	15	730
Rock, red	30	760
Shale, black	30	790
Limestone	15	805
Shale, brown	35	840
Rock, red	10	850
Shale, brown, show of oil	10	860
Shale, white	15	875
Shale, brown	35	910
Shale, blue	30	940
Limestone	15	955
Rock, red	5	960
Limestone	10	970
Shale, white	55	1,025
Limestone, white	95	1,120
Rock, red	5	1,125
Shale, white	65	1,190
Limestone, white	20	1,210
Shale, white	40	1,250
Rock, red	10	1,260
Shale, white	30	1,290
Water sand	40	1,330
Shale, white	10	1,340
Limestone, white	85	1,425
Shale, black	75	1,500
Limestone	60	1,560
Lime, sandy	7	1,567
Shale, black	28	1,595
Limestone, hard, shell	5	1,600
Shale, soft, dark	85	1,685
Limestone shells	10	1,695
Shale, gray	5	1,700
Limestone shells	10	1,710
Shale, soft, dark	60	1,770
Do	20	1,790
Shale, sandy, and water	25	1,815
Water sand	20	1,835
Limestone shells and sand	40	1,875
"Slate," sandy, very hard	20	1,895
Limestone, very hard	45	1,940
Shale, gray	10	1,950
Limestone	10	1,960
Shale, dark	35	1,995
Limestone, hard	5	2,000
Rock, red	20	2,020
Limestone shell	5	2,025
Shale, gray	5	2,030
Limestone	35	2,065
Shale, blue	25	2,090
Shale, dark	15	2,105
Water sand	30	2,135
Limestone, sandy	15	2,150
Shale, blue	40	2,190
Shale, gray	15	2,205
Shale, dark	35	2,240
"Slate," dark	10	2,250
Limestone (3 boilers water per hour)	20	2,270
Shale, dark	25	2,295

Log of Reynolds No. 1 well, 3 miles north and half a mile west of Albany, Shackelford County, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand, dry, gray	9	2,304
Limestone	9	2,313
Shale, dark	282	2,595
Limestone	5	2,600
Sand, gray, dry	5	2,605
Limestone	20	2,625
Lime, sandy, water	2	2,627
Lime	38	2,665
Sand, dry	5	2,670
Lime	87	2,757
Sand	20	2,777
Shale, black	83	2,860
Limestone, black	5	2,865
Shale, black	35	2,900
Limestone, water 4 boilers	5	2,905
Shale, black (top)	7	2,912
Lime	13	2,925
Shale, gray	87	3,012
Limestone	73	3,085
Shale, blue	35	3,120
Limestone, blue	30	3,150
Water sand	7	3,157
Limestone		

Log of well on Cauble ranch, in Shackelford County, Tex., near northeast corner of county (north of Clear Fork).

[Drilled May 31 to Sept. 16, 1912.]

	Thickness.	Depth.
	Feet.	*Feet.*
"Cellar"	10	10
Clay, red	80	90
?	10	100
Shale	40	140
Limestone, white	5	145
Shale, white	13	158
Limestone, hard	3	161
Shale, white	94	255
Rock, red	5	260
Sand, white, salt water	25	285
Limestone, white, soft	35	320
Rock, red, top	50	370
Limestone, white	10	380
Shale, white	55	435
Limestone, black, hard	10	445
Shale, white	50	495
Rock, red	25	520
Sand, gray (little gas)	10	530
Shale, white	70	600
Rock, red	12	612
Limestone, white	18	630
Shale, white	20	650
Limestone, white, hard	10	660
Shale, white	30	690
Sand, gray, dry	10	700
Rock, red	30	730
Shale, white	70	800
Sand, white (salt water)	25	825
Shale, white	75	900
Shale, black, soft	20	920
Shale, white	150	1,070
Rock, red	5	1,075
Sand, black	52	1,127
Shale, black	11	1,138
Limestone shells	24	1,162
Limestone, white	22	1,184
Rock, red	36	1,220
Sand (salt water)	18	1,238
Shale, white	46	1,284
Limestone, white	4	1,288

Log of well on Cauble ranch, in Shackelford County, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Rock, red	42	1,330
Limestone, dark	20	1,350
Rock, red	35	1,385
Limestone, gray	25	1,410
Limestone, black	30	1,440
"Slate," white	50	1,490
Sand, black	40	1,530
Shale, black	139	1,669
Limestone, white	21	1,690
Shale, black	270	1,960
Limestone, gray, little water	6	1,966
Limestone, white	34	2,000
Limestone, black	12	2,012
Shale, black	28	2,040
Limestone, hard, gray	160	2,200
Shale, black	40	2,240
Limestone, hard, shells	12	2,252
Shale, black	26	2,278
Limestone, gray, and hard shells	6	2,284
Shale, black	11	2,295
Sand, black, salt water	18	2,313
Limestone, white, hard	17	2,330
Shale, black	35	2,365
Limestone, gray	12	2,377
Shale, black	63	2,440
Limestone, gray	6	2,446
Shale, black	9	2,455
Limestone, gray	25	2,480
Shale, black	20	2,500
Limestone, gray, hard	60	2,560
Shale, black	15	2,575
Limestone, black, top	4	2,579
Shale, white	61	2,640
Limestone, gray, hard	130	2,770
Shale, blue	37	2,807
Limestone, gray, shells	18	2,825
Shale, black	20	2,845
Limestone shells	30	2,875
Shale	42	2,917
Top sand	31	2,948
Sand, black	30	2,978

Log of Nelson No. 1 well, 3 miles north and 1 mile west of Moran, Tex., 200 feet north of south line and 800 feet west of east line Nelson lease.

[J. M. Guffey Petroleum Co. (½), Treat Crawford (¼), Lone Star (¼). Contractors, Halfest & Easton. Drilled Nov. 16, 1914, to Feb. 11, 1915. Casing: 12½ inch, 455 feet; 10 inch, 1,092 feet; 8 inch, 1,550 feet; 6 inch, 1,897 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface soil	35	35
Shale, blue	10	45
Rock	5	50
Limestone shell	3	53
Brown mud	5	58
Limestone shell	7	65
Brown mud	20	85
Limestone shell	5	90
Shale, blue	5	95
Rock, red	5	100
"Slate," white	20	120
Shale, blue	10	130
Limestone	6	136
Shale, blue	19	155
Limestone	10	165
Shale, white	35	200
Sand, show of oil	10	210
Rock, red	20	230
Brown mud	10	240
Rock, red	10	250
Brown mud	10	260
Limestone	15	275
Shale, brown	20	295

Log of Nelson No. 1 well, 3 miles north and 1 mile west of Moran, Tex.—Con.

	Thickness.	Depth.
	Feet.	*Feet.*
Rock, red	5	300
Shale, white	35	335
Limestone	5	340
Sand	10	350
"Slate," white	5	355
Limestone	27	382
Shale, black	18	400
Shale, light	30	430
Sand, salt water (hole full)	30	460
Brown mud	10	470
Shale, blue	10	480
Shale, brown	15	495
Shale, blue	5	500
Limestone	6	506
Shale, dark	12	518
Limestone	17	535
Shale, dark	15	550
Shale, light	5	555
Limestone	5	560
Shale, dark	55	615
"Slate"	5	620
Limestone	5	625
Shale, dark	25	650
Limestone	10	660
Slate, white	5	665
Shale, dark	15	680
Sand, salt water (hole full)	20	700
"Slate," dark	50	750
"Slate," white	30	780
Shale, dark	10	790
Shale, brown	42	832
Shale, dark	48	880
"Slate," white	20	900
Shale, light	20	920
Limestone	8	928
Shale, dark	72	1,000
Shale, black	5	1,006
Shale, white	20	1,025
Sand	30	1,055
Water at 1,032 feet.		
Shale, white	90	1,145
Do	7	1,152
Limestone ("big lime")	43	1,196
Shale, light	50	1,245
Limestone	40	1,285
Water at 1,255-1,285 feet.		
Shale, black	15	1,300
Limestone	153	1,453
Water at 1,342-1,372 feet.		
Slate, white	5	1,458
Lime, sandy	15	1,473
Shale, dark	27	1,500
Limestone	8	1,508
Limestone, sandy, water	4	1,512
Limestone	45	1,557
Shale, light	23	1,580
Sand, water	10	1,590
Shale, light	15	1,605
Shale, dark	95	1,700
Limestone shells	5	1,705
Shale, light	37	1,742
Limestone	5	1,747
Shale, blue	45	1,792
Limestone	23	1,815
Sand (hole full of water)	22	1,837
Shale, light	60	1,897
Limestone	33	1,930
Shale	13	1,943
Limestone	12	1,955
Shale, white	7	1,962
Shale, black	6	1,968
Slate, dark	32	2,000
Shale, light	25	2,025
Shale, dark	45	2,070
Limestone shells	3	2,073
Shale, light	32	2,106
Sand	15	2,120
Hole full of water. Abandoned.		

PALO PINTO GAS SHOWINGS.

The possibility of developing gas or oil in the region north of Palo Pinto has recently been discussed by Wegemann,[1] who suggested that tests be made of deeper sands in the vicinity of the Dalton well on the Kyle Mountain anticline. The structure of the region, including a plunging anticline and minor lateral folds, was correctly described by Mr. Wegemann though, through inadvertence, it was erroneously contoured on the map. A revision of the contouring has recently been published by L. J. Pepperberg.[2] Mr. Wegemann suggests a test of a small anticline 4 miles north of the Brazos River bridge on the Palo Pinto-Graford road, should an adequate test of the Kyle Mountain anticline prove successful.

Gas showings of greater or less size have been found in various parts of Palo Pinto County. A good showing of both gas and oil has been found in a 2,600-foot well recently drilled on the Frank Corn land in the southeast part of the county. The first notable showing in the county is said to have been found in a water well 4 miles north of Palo Pinto. A good oil well and also a gas well having a capacity of 500,000 cubic feet were reported in December, 1915.

A log of a recently drilled deep well to illustrate the strata encountered in drilling in this county is given below.

Log of well No. 1 on Holt ranch, 6 miles southwest of Salesville, Sykes & Pallaint, operators.

[Contractor, L. C. Hevick. Drilled September, 1915.]

	Thickness.	Depth.
	Feet.	*Feet.*
Red dirt	4	4
Shale in small shell	46	50
Shale, blue	40	90
Shell, lime	10	100
Shale, blue	40	140
Shell	8	148
Shale	47	195
Shell	5	200
Shale, blue	45	245
Lime shell	10	255
Shale, blue	125	380
Water sand, fresh	20	400
Shale	20	420
Water sand, fresh	20	440
Shale	120	560
Lime shell	12	572
Water sand	283	855
"Slate"	39	894
Water sand, salt	136	1,030
"Slate"	75	1,105
Water sand, salt	10	1,115
"Slate"	55	1,170
Lime shell	6	1,176
"Slate"	29	1,205
Shale, sandy	20	1,225
Shale, blue	10	1,235
Shale	140	1,375

[1] Wegemann, C. H., A reconnaissance in Palo Pinto County, Tex., with special reference to oil and gas: U. S. Geol. Survey Bull. 621, pp. 51–59, 1915.

[2] Pepperberg, L. J., Western Engineering, vol. 6, No. 6, pp. 252–254, San Francisco, Dec., 1915.

Log of well No. 1 on Holt ranch, 6 miles southwest of Salesville—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand	25	1,400
Do	40	1,440
Do	130	1,570
"Slate"	60	1,630
Water sand	8	1,638
Shale, sandy	65	1,703
Shelly lime	37	1,740
Sand, show of oil	5	1,745
Shelly lime	45	1,790
Shale	15	1,805
Shell	5	1,810
Shale	85	1,895
Sand, dark, dry	20	1,915
Shale	12	1,927
Sand, with little water	19	1,946
Shale	56	2,002

SCATTERED SMALL GAS POOLS AND SHOWINGS.

Small showings of gas have been found in a great many wells in the region north and northwest of Fort Worth, but most of these probably have no connection with any considerable gas pool. The experience of the prospectors justifies this inference. It is commonly remarked that little puffs of gas may come from any well drilled in northern Texas, but that they have no significance. At several places, however, noteworthy quantities of gas have been found, though further prospecting has shown that the pools are small.

A brief examination was made of a small area just north of Mankins, about 20 miles southwest of Wichita Falls, where two or three showings of oil are reported in the log of an 850-foot well, but no good indications of a gas reservoir were found. Dundee, 15 miles farther southwest, where a 2,000-foot dry hole was recently drilled, was also visited. The rock outcrops a few miles south of Dundee are much better than at Mankins, and apparently the beds at both places lie nearly flat.

At Graham, in Young County, some gas was found only a few hundred feet below the surface, and as a consequence several deep test wells were sunk, the log of one of which is given below.

Driller's log of Corsicana Petroleum Co.'s well No. 1 on C. N. Keen farm, in Young County, Tex.

[Contractors, Halfest & Easton. Drilled July 4 to Oct. 5, 1912. Casing: $13\frac{1}{4}$ inch, 415 feet; 10 inch, 840 feet; $8\frac{1}{4}$ inch, 1,022 feet; $6\frac{1}{4}$ inch, 1,762 feet; $5\frac{3}{16}$ inch, 2,024 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Sand	30	30
"Slate"	75	100
Sand	35	145
"Slate"	25	170
Sand	20	195
"Slate"	105	305

Driller's log of Corsicana Petroleum Co.'s well No. 1 on C. N. Keen farm, in Young County, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Red rock	75	375
Coal	5	380
White cave	35	415
"Slate"	55	470
Sand	40	510
"Slate"	33	543
Sand	15	558
"Slate"	212	770
Sand	20	790
Cave	50	840
"Slate"	115	955
Limestone	25	980
Sand	12	992
Cave	30	1,022
"Slate"	60	1,082
Do	48	1,130
Limestone	40	1,170
"Shell"	5	1,175
Limestone	8	1,183
"Slate"	229	1,412
Limestone	13	1,425
"Slate"	10	1,435
Limestone	15	1,450
"Slate"	55	1,505
Limestone	45	1,550
Sand	70	1,620
"Slate"	30	1,650
Sand	25	1,675
"Slate"	10	1,685
Sand	35	1,720
"Slate"	10	1,730
Sand	10	1,740
"Slate"	85	1,825
Sand	8	1,833
"Slate"	17	1,850
Sand	25	1,875
"Slate"	10	1,885
Sand	15	1,900
"Slate"	540	2,440
Limestone	10	2,450
"Slate"	69	2,519
Sand	20	2,539
"Slate"	41	2,580
Limestone	10	2,590
"Slate"	23	2,613
Limestone	10	2,623
"Slate"	2	2,625
Limestone	11	2,636
"Slate"	124	2,760
Sand	10	2,770
"Slate"	5	2,775
Sand	21	2,796
Bottom dry. Abandoned.		

Strong showings of gas are reported from depths ranging from 255 to 696 feet in a 2,171-foot well drilled by the Producers Oil Co. on the R. F. Arnold farm 3½ miles south of Newcastle in Young County. The gas showings here and in the Murry well, about 8 miles distant, are said by some to have been decidedly the best so far found in Young County.

Several wells in Archer County have yielded small quantities of gas. At one well the gas is reported to have caught fire and burned with a flame many feet high, but these reports were not confirmed.

Showings of oil have also been reported in some test wells, the logs of three such wells being as follows:

Log of Corsicana Petroleum Co.'s well No. 1 on R. J. Garvey farm, in Archer County, Tex.

[Contractors, J. W. Dyson & Co. Drilled May 11, 1912, to July 12, 1912. Casing: 13¼ inch, 385 feet; 10 inch, 810 feet; 8¼ inch, 1,306 feet; 6⅝ inch, 2,325 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Red mud	20	20
Sand, white	10	30
Blue mud	30	60
Red mud	20	80
Sand	20	100
Blue mud	40	140
Red mud	25	165
Sand	10	175
Blue mud	70	245
Red mud	15	260
Sand	40	300
Red mud	10	310
Blue mud	30	340
Shale	25	365
Red mud	20	385
??	60	445
Shale	65	510
Limestone, white	15	525
Shale	25	550
Sand	30	580
Red mud	25	605
Sand	5	610
Limestone, hard	50	660
Shale	30	690
Do	50	740
Limestone	20	760
Sand	10	770
Shale and mud	60	830
Sand, show of oil and gas	20	850
Shale, white	60	910
Shale, sandy	30	940
Shale, dark	70	1,010
Shale, white	30	1,040
Shale, dark	50	1,090
Sand, white	20	1,110
Limestone	40	1,150
Shale	90	1,240
Lime tone and shale	45	1,285
Limestone	30	1,315
Shale and limestone	240	1,555
Limestone	20	1,575
Shale	30	1,605
Limestone	10	1,615
Shale, dark	150	1,765
Shale, white	50	1,815
Sand, dark	10	1,825
Shale	85	1,910
Shale, sandy	140	2,050
Shale, dark	140	2,190
Shale, white	90	2,280
Limestone, dark	20	2,300
Shale	20	2,320
Sand	5	2,325
Shale	5	2,330
Sand	20	2,350
Shale	27	2,377
Bottom dry. Abandoned July 18, 1912.		

Driller's log of Corsicana Petroleum Co.'s well No. 3 on M. P. Andrews farm, in Archer County, Tex.

[Contractor, E. W. Morgan. Drilled September 3 to November 10, 1912. Casing: 13½ inch, 430 feet; 10 inch, 898 feet; 8 inch, 1,315 feet; 6 inch, 1,600 feet; 5 3/16 inch, 2,100 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Red mud, sand, etc	180	180
Sand, water	20	200
Red rock	90	290
Sand, water	20	310
Red rock	40	350
Sand, water	80	430
Shale, light	10	440
Red rock	15	455
"Slate," blue	95	550
Sand, dry	20	570
"Slate," blue	10	580
Sand, dry	10	590
"Slate," light	50	640
Limestone	15	655
"Slate," light	5	660
Sand, dry	30	690
Shale, light	20	710
Sand, water	40	750
"Slate," light	25	775
Sand, water	15	790
Shale, light	102	892
Limestone, hard	6	898
Shale, light	13	911
Sand, oil	13	924
Red rock	11	935
Sand, dry	10	945
Red rock	15	960
Shale, light	290	1,250
Sand, water	60	1,310
"Slate," white	90	1,400
Limestone	10	1,410
"Slate," blue	20	1,430
Shale, light brown	10	1,440
Limestone, white	10	1,450
Shale, blue	10	1,460
Limestone	6	1,466
Shale, blue	10	1,476
Limestone, white	20	1,496
Shale, light	29	1,525
Sand, water	30	1,555
Shale	10	1,565
Sand, water	115	1,680
Shale, light	30	1,710
Limestone	15	1,725
Shale, light	45	1,770
Limestone	25	1,795
Shale, light	165	1,960
Sand, water	80	2,040
Shale, light blue	10	2,050
Sand, water	10	2,060
Shale, light	30	2,090
Shale, sandy	110	2,200
Shale, dark	150	2,350
Shale, light	50	2,400
Limestone	5	2,405
Shale, light	10	2,415
Sand, dry	5	2,420
?, light	95	2,515
Sand, water	5	2,520
Dry. Abandoned May, 1913.		

Driller's log of Corsicana Petroleum Co.'s well No. 2 on Cora Harmonson farm, in Archer County, Tex.

[Contractors, J. W. Dyson & Co. Drilled July 28 to Dec. 12, 1912. Casing: wooden conductor, 357 feet; 13½ inch, 357 feet; 10 inch, 711 feet; 8 inch, 1,332 feet; 6⅝ inch, 1,356 feet; 5$\frac{3}{16}$ inch, 1,590 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface	90	90
Sand, gray	10	100
Red rock	85	185
Sand, gray	20	205
Red rock	45	250
Slate	55	305
Red rock	2	307
Sand, water	83	390
Shale, blue	15	405
Red rock	10	415
Shale, blue	8	423
Red rock	7	430
Sand, gray, and coal	25	455
Red rock	85	540
Sand, gray	10	550
Sand, water	65	615
"Slate," white	5	620
Limestone	20	640
"Slate," gray	5	645
Sand, water	35	680
"Slate," gray	6	686
Limestone	66	752
"Slate," gray	123	875
Limestone	10	885
Shale	31	916
Sand (show of oil)	5	921
Shale	9	930
Limestone	5	935
Shale	17	952
Limestone	5	957
Shale and water	118	1,075
Sand	10	1,085
Shale	60	1,145
Sand	8	1,153
Shale, blue	72	1,225
Limestone	5	1,230
"Slate"	8	1,238
Sand, water	22	1,260
"Slate"	5	1,265
Sand, water	5	1,270
Limestone	8	1,278
Sand, water	37	1,315
"Shale"	82	1,397
Limestone	13	1,410
"Slate"	30	1,440
Limestone	10	1,450
"Slate"	5	1,455
Limestone	10	1,465
"Slate"	5	1,470
Limestone	25	1,495
Shale	25	1,520
Sand	40	1,560
Shale	155	1,715
Limestone	12	1,727
Shale	43	1,770
Limestone	15	1,785
Shale	15	1,800
Limestone	35	1,835
Shale	25	1,860
Limestone	15	1,875
Shale, blue	63	1,938
Abandoned May 1, 1913.		

Small showings of both gas and oil in Montague County have been reported, and a deep well has recently been sunk north of the town of Montague. A log of this well is given below.

Log of C. B. Shaffer well No. 1 on J. D. Jameson farm, Montague County, Tex.

[Drilled in 1915 with cable tools. Contractor, C. A. Steelsmith. Casing: 12½ inch, 638 feet (underreamed from 512 feet); 10 inch, 1,101 feet (underreamed from 780 feet); 8 inch, 1,704 feet (underreamed from 1,253 feet); 6⅝ inch, 22 feet (underreamed from 1,943 feet).]

	Thickness.	Depth.
	Feet.	*Feet.*
"Cellar" (sandy soil), soft	7	7
Sand, hard	3	10
Red rock, soft	15	25
"Slate," soft, white	50	75
Shale, soft, blue	90	165
Sand, soft, gray, much fresh water	45	210
Shale, soft, red	15	225
Shale, soft, blue	55	280
Sand, soft, gray, a little fresh water	10	290
"Slate," soft, white	10	300
Shale, soft, red	5	305
"Slate," soft, white	5	310
Sand, soft, gray, a little fresh water	5	315
Shale, soft, red	20	335
"Slate," soft, white	20	355
Sand, soft, gray, a little fresh water	15	370
Shale, soft, blue	10	380
Sand, soft, gray, a little fresh water	15	395
Shale, soft, blue	35	430
Sand, soft, gray, a little fresh water	10	440
Shale, soft, blue	70	510
Sand, soft, gray, a little fresh water	20	530
Shale, soft, blue	40	570
"Slate," soft, white	30	600
"Slate," soft, black	10	610
Shale, soft, blue	23	633
Limestone shell, hard, white	7	640
Shale, soft, blue	20	660
Sand, soft, gray, a very little fresh water	15	675
Shale, soft, pink	15	690
Shale, soft, brown	10	700
Shale, soft, blue	65	765
Sand, soft, gray, much fresh water	25	790
Shale, soft, blue	15	805
Shale, soft, pink	25	830
Shale, soft, red	20	850
Shale, soft, blue	10	860
Sand, soft, gray, much fresh water	20	880
Shale, soft, blue	10	890
Twelfth sand, soft, gray, fresh water	35	925
Shale, soft, blue	5	930
Thirteenth sand, soft, gray, fresh water	30	960
Shale, soft, blue	25	985
Shale, soft, red	25	1,010
Fourteenth sand, soft, gray, fresh water	25	1,035
Shale, soft, blue	5	1,040
Fifteenth sand, soft, gray, fresh water	45	1,085
Shale, soft, blue	5	1,090
Sixteenth sand, hard and sharp, gray, fresh water	10	1,100
Shale, soft, gray	5	1,105
Seventeenth sand, soft, gray, fresh water	10	1,115
Shale, soft, blue	15	1,130
Eighteenth sand, soft, gray, brackish water	35	1,165
Shale and limestone shells, soft and hard, gray	15	1,180
Nineteenth sand, soft, gray, brackish water	25	1,205
Shale, soft, blue	20	1,225
Twentieth sand, soft, gray, salt water	20	1,245
Shale, soft, blue	30	1,275
Twenty-first sand, soft, gray, slight salt water	30	1,305
Shale, soft, blue	25	1,330
Twenty-second sand, soft, gray, dry and coarse	8	1,338
Shale, soft, blue	17	1,355
Twenty-third sand, soft, gray, dry and coarse	8	1,363
Shale, soft, blue	82	1,445
Twenty-fourth sand, soft, gray, dry	7	1,452
Shale, soft, blue	48	1,500
Twenty-fifth sand, soft, gray, salt water	25	1,525
Shale, soft, blue	70	1,595
Twenty-sixth sand, soft, gray, salt water	20	1,615
Shale, soft, blue	60	1,675
Twenty-seventh sand, soft, black, dry and coarse	20	1,695
Shale, soft, black	15	1,710
Lime, black, hard	20	1,730
Shale, soft, black	35	1,765
Lime, hard, gray	10	1,775

Log of C. B. Shaffer well No. 1 on J. D. Jameson farm, Montague County, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale, soft, blue	55	1,830
Twenty-eighth sand, soft, gray, slight salt water	15	1,845
Shale, soft, blue	10	1,855
Lime, hard, white	20	1,875
Shale, soft, gray	40	1,915
Lime, hard, white	10	1,925
Shale, soft, gray	30	1,955
Lime, hard, white	15	1,970
Shale, soft, gray	50	2,020
Twenty-ninth sand, soft, gray, much salt water	20	2,040
Shale, soft, gray	35	2,075
Lime, hard, white	10	2,085
Shale, soft, gray	15	2,100
Lime, hard, white	10	2,110
Shale, soft, gray	20	2,130
Thirtieth sand, hard, gray, much salt water	10	2,140
Shale, soft, gray	20	2,160
Thirty-first sand, soft, gray, much salt water	15	2,175
Shale, soft, gray	5	2,180
Thirty-second sand, soft, gray, much salt water	40	2,220
Shale, soft, gray	5	2,225
Thirty-third sand, hard, gray, much salt water	15	2,240
Shale, soft, gray	5	2,245
Thirty-fourth sand, soft, brown, much salt water	1	2,246

Small showings of both oil and gas are reported from Cook and Denton counties and a well 2,365 feet deep has recently been sunk about 6 miles south of Denton by J. S. Darnall, of Denton, and P. L. Tippett, of Gainesville. These men are drilling another well between Myra and Red River in Cook County.

Small showings of oil are reported in some wells in the eastern part of Dallas County, but on the whole the sands underlying Dallas and Tarrant counties seem to have lost all the oil, gas, and salt water they ever had and are now filled with fresh water. A mile east of Paradise in Wise County good showings of oil are reported and a log of one well follows:

Driller's log of well 1 mile east of Paradise.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	5	5
Quicksand	35	40
Sand, white, water	20	60
Sand and shells	10	70
Sand, water	10	80
"Gipp rock"	4	84
"Trivally" sand	14	98
Sand rock	2	100
Pack sand	10	110
Gumbo, red	6	116
Sand rock	6	122
Sand rock, "crystallized"	3	125
Pack sand	1½	126½
Gumbo	1½	128
Shale, blue	6	134
Pack sand; set 10-inch casing at 154 feet	20	154
Sand rock	3½	157½

Driller's log of well 1 mile east of Paradise—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Pack sand	3	160½
Gumbo	4½	165
Sand rock	5	170
Gumbo	3	173
Sand rock	8	181
Gumbo	9	190
Shale, blue	56	246
Sand rock, hard, brown	26	272
Shale, blue	20	292
Gumbo, blue	5	297
Shale, blue	12	309
Sand rock	1	310
Shale, blue	18	328
Lime rock, blue	2	330
Gas rock	3	333
Shale, blue	7	340
Gumbo, blue	4	344
Sand rock	29	373
Gumbo	1	374
Sand, salt water	2	376
Sand rock, hard	23	399
Gumbo	4	403
Shale, blue	4½	407½
Lime rock	253	660½
Chalk (No. 1)	13	673½
Sand, blue	2½	676
Shale, blue	10	686
Sand, showing oil	30	716
Gumbo	26	742
Lignite	4	746
Shale, blue, dark color	2	748
Sand rock, gray	12	760
Shale, blue	7	767
Sand, salt water; set 8-inch pipe	1	768
Sand rock, hard, white	46	814
Gumbo	34	848
Shale, blue	8	856
Shale, blue, with streaks blue sand	10	866
Sand, blue	5	871
?	46	917
Sand, hard packed	3	920
Sand rock, hard	3	923
Packed sand	3	926
Sand rock, gray (soft place in sand)	2	928
Lime rock, soft	6	934
Shale, hard, gray	7	941
Sand rock, gray, and show of gas	7	948
Packed sand, hard	20	968
Shale, hard, blue	144	1,112
Sand rock	4	1,116
Shale, blue, and lime shells	114	1,230
Soft coal (like asphalt)	1	1,231
Shale, blue	9	1,240
Sand rock, gray	6	1,246
Shale, hard, blue	44	1,290
Sand rock, soft, gray, and quartz	6	1,296
Shale, blue, hard	24	1,320
Sand rock, gray	2	1,322
Shale, blue	2	1,324
Sand rock, hard, gray	8	1,332
Shale, hard, blue	3	1,335
Coal, cannel	2	1,337
Shale, blue	5	1,342
Shale and sand shells	6	1,348
Shale, blue	39	1,387
Shale, hard, gray	4	1,391
Sand rock, gray	16	1,407
Shale, hard, blue	26	1,433
Sand rock, soft, gray	3	1,436
Shale, hard, blue	4	1,440
Sand rock, gray, and gas (very porous rock)	16	1,456
Shale and hard limestone shells	14	1,470
Shale, gray	10	1,480
Sand, soft, white	5	1,485
Shell, hard, limestone	10	1,495
Shale, blue	5	1,500

In the southwest corner of Throckmorton County a gas well reported to have a capacity of 20,000,000 cubic feet is 1,060 feet deep. Several other wells have been drilled, some to much greater depth, but none have been successful.

UNDISCOVERED POOLS.

Geologic indications.—The geology of the region extending north and west of Dallas and Fort Worth for 150 miles is, as already stated, generally favorable to the origin, accumulation, and preservation of gas and oil pools. All considerations, both practical and theoretical, point to the existence of undiscovered pools both of gas and of oil in the region. The favorable geologic conditions may be summarized as follows:

1. The rocks of the region belong to the Carboniferous and Cretaceous systems, which contain much gas and oil in other regions. Such rocks as the pre-Cambrian, which nowhere contain valuable pools of gas or oil, are not found, or lie so far below the surface that they may be left out of consideration.

2. The general structure is favorable. The layers of rock have the form of a broad, shallow basin or geosyncline, and most of the gas and oil of the world occur in such general basins. The rocks lie nearly flat and at some places, particularly between Fort Worth and Red River, have a broad terrace form.

3. The details of structure are locally favorable. Though the beds lie nearly flat, their general attitude is at many places modified by irregularities of various kinds, and here and there they are undoubtedly arched up into well-developed domes and anticlines, as has been shown by observations made in similar basins elsewhere and by the conditions existing in those parts of this basin that have been tested.

4. The chemical composition of the rocks shows that they may have been the source of large quantities of oil and gas. Carbonaceous sediments, including coal, though not so abundant as in some other regions, are very common.

5. The physical nature of the rocks also shows that they are well suited to accumulate and retain gas and oil pools. They include many layers of open-textured sand of various degrees of porosity, in more or less lenticular beds. These sands make up less than half of the rock, a fact favorable to their retention of pools of oil and gas, because it makes the washing out of the beds with fresh water difficult or impossible.

6. The history of the rocks has been favorable to the accumulation and retention of pools. With the exception of those underlying Dallas, they have apparently not been tilted back and forth until

all the original fluids in the sands have migrated elsewhere. Salt water, which is considered an indication of slight or no underground circulation, is found almost throughout the region, and it may be fossil sea water which has not been shifted far since the beds were deposited.

7. The rocks have been under sufficient pressure to induce the degree of metamorphism required to separate the hydrocarbons that make up gas and oil, but have not been so much compressed as to drive these fluids out of the region and leave nothing but carbonized remains. David White, in discussing this subject recently, has pointed out that the quality of gas and oil found in any rocks shows a relation to the stresses to which the rocks have been subjected and has suggested that gas pools are likely to be most numerous on the sides of an oil region that lie nearest to regions in which the rocks have undergone greater stresses. According to this principle, gas pools should be most numerous on the east side of this oil and gas region.

The discovery of new pools may undoubtedly be hastened by careful studies of the rocks, made to determine the most promising places for drilling. Without such assistance in finding pools, the cities of Fort Worth and Dallas will probably fail to obtain abundant supplies of natural gas unless they draw supplies from Oklahoma or other distant fields. As the country is developed, and as the oil and gas resources gradually become exhausted, more wildcat wells will no doubt be drilled and greater care will be taken to drill them in the most favorable places. The search for gas and oil pools should begin with domes and anticlines, for they are by far most likely to contain such pools. Later explorations should extend to structures less favorable, and finally to regions in which the underground structure can not be determined because significant outcrops are poor or are lacking.

Inferences based on experience and on the doctrine of chances.— The proportion of wildcat wells that have been successful in the region under discussion indicates that if it were practicable to make tests of each square mile, a good many more gas pools would be found. Such a series of tests is, of course, as yet out of the question, but illuminating inferences may be drawn from the results of the somewhat random wildcatting and the proportion of successful wells. The importance of these tests becomes more obvious when the law of probabilities is applied to them and the fact is remembered that in some counties, especially Parker, probably not a single deep test well has been drilled. If a township were known to contain a pool of oil a mile across, the chances of finding that pool by a random well would, of course, be 1 in 36. If a county covering 1,000 square miles contains

one pool 3 or 4 miles across or having an area of 10 square miles the chances of finding the pool by a random test are 1 in 100. Other considerations, of course, enter into the problem, such as the fact that the well must be sufficiently deep and drilled with sufficient care to make an adequate test; nevertheless a single unsuccessful wildcat well

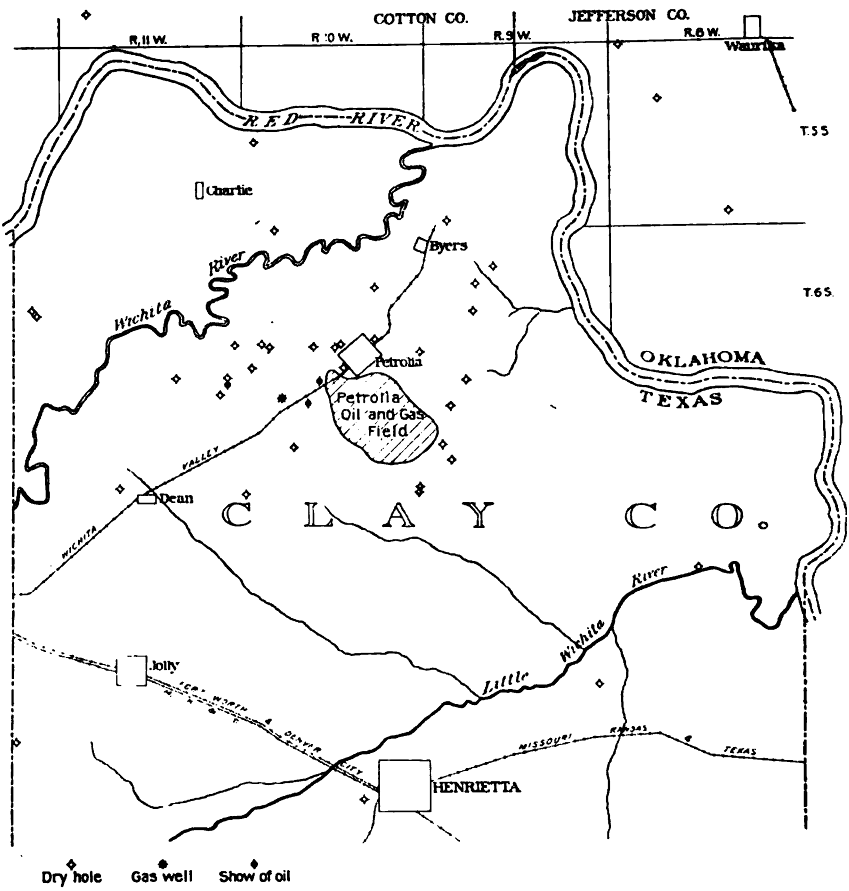
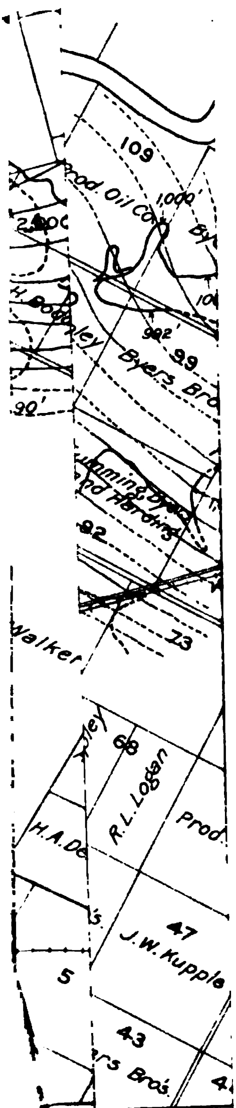


FIGURE 3.—Map showing distribution of deep wells in the northern half of Clay County and the degree of thoroughness of the testing, independent of geologic conditions.

drilled at random does not throw a great deal of light on the existence of gas and oil pools in a considerable area.

Figure 3 shows the distribution of deep tests in the northern half of Clay County, where such tests are unusually abundant. It should be observed that even in this region, which has been rather fully tested by wells, there are large areas in which no test wells have been drilled.


109
Prod. Oil Co.
1,000'
992'
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Walker
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R.L. Logan
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J.W. Kupple
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C UNTY, T

AREAS SURVEYED TO FIND FAVORABLE STRUCTURE.

BETWEEN WICHITA VALLEY RAILWAY AND WICHITA RIVER.

A plane-table survey (see Pl. IV) of a belt extending from a point northeast of Byers to Dean, which, however, shows some gaps where exposures are poor, was made by H. M. Robinson and the writer. The survey consisted principally in running lines of levels along outcropping contacts of sandstone and shale, the sandstone being the upper member in some places and the lower member in others. Account was also taken of dips, of benches made by hard layers, and of fragments of rock in the soil at places where outcrops were poor or lacking. Where the beds at the horizon contoured were concealed it was traced by means of outcropping beds above or below.

The rocks near Byers dip, on the whole, to the northeast; those north of Petrolia to the north, and those near Dean to the northwest. In other words, the general dips of the strata are away from the Petrolia field. The general dips are modified, as shown in Plate IV, by local dips in various directions, but no well-developed anticlines, domes, or other structures favorable to the accumulation of gas were found anywhere in the belt examined. Nowhere in the belt is there a pronounced dip opposite the main dip. Some places, however, are more promising than others, and if, in addition to the several unsuccessful tests made in this belt, most if not all of which are indicated on the map, other wells were to be sunk it would seem wise to sink them 1 to 2 miles north of Petrolia, 1 to 2 miles west of Dean, and 3 to 4 miles west of Petrolia. The strata and physiographic features at the place last named show that the rocks on the north dip to the north and those on the west dip to the west. A fairly well developed basin lies about 2 miles north of this place.

Apparently, the Petrolia anticline involves not only the rocks in the oil and gas field but also those in a large surrounding territory, for the search for other anticlines along the south side of Wichita River was not only fruitless but the strata everywhere rise toward the oil and gas field. The anticline 5 miles east of Byers, described by Wegemann,[1] may be the east end of the Petrolia anticline and may be lower than the part in the oil and gas field, for a well recently drilled 3 miles southwest of Waurika, near the crest of the east end of this anticline, was unsuccessful. A log of this well and a log of a well northeast of Waurika, which shows much less red rock, are given on page 66. The log of a deep well near Byers is also given, and these three and the wells in the Petrolia oil and gas field form a row of wells along the axis of the anticline.

[1] Wegemann, C. H., Anticlinal structure in Cotton and Jefferson counties, Okla.: U. S. Geol. Survey Bull. 602, p. 98, 1915.

Log of lower part of well 3 miles southwest of Waurika, Okla., in SE. ¼ sec. 8, T. 5 S., R. 8 W.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale, blue	3	1,113
Shale, red	12	1,125
Shale, blue	10	1,135
Shale, sandy	10	1,145
Shale, red	60	1,205
8-inch casing set at 1,204 feet.		
Shale, blue	10	1,215
Sand, water	10	1,225
Shale, blue	15	1,240
Shale, red	25	1,265
Shale, blue	10	1,275
Red bed	35	1,310
Shale, blue	29	1,339
Sand	15	1,354
Shale, blue	34	1,388
Sand	21	1,409
Shale, blue	8	1,417
Sand	3	1,420
Shale, blue	4	1,424
Sand, salt water	10	1,434
Shale, blue	13	1,447
Sand	4	1,451
Shale, red, gumbo	7	1,458
Shale, brown	3	1,461
Shale, brown, sandy	24	1,485
Limestone	4	1,489
Shale, blue	11	1,500
Shale, sandy, blue	5	1,505
Sand	12	1,517
"Slate," black	27	1,544
Shale, blue	11	1,555
Sand, dry	20	1,575
Shale, white	5	1,580
Sand, dry	5	1,585
Shale, blue	15	1,600
Sand, water	7	1,607
Limestone, hard	21	1,628
Shale, black, hard	4	1,632
Sand, water	2	1,634
Limestone, sandy	9	1,643
Sand, white	11	1,654
"Slate," black	4	1,658
Shale, blue	20	1,678
Sand, oil, and water (10 barrels oil)	10	1,688
Shale, black	22	1,710
Shale, blue	155	1,865
Sand, water, and showing of oil	111	1,976
Shale, black	16	1,992
Limestone, sandy	13	2,005
Sand, fine	15	2,020
Cave shale, blue-gray, and sandstone	10	2,030
Similar but pinkish	10	2,040
Shale, gray	20	2,060
Shale, hard, gray, with fossil shells	40	2,100
Shale, sandy, gray (fine drilling, no caving)	150	2,250
Shale, sandy	....	....

Began to get loadstone at 400; tools showed strong magnetization.

Partial log of Kauerauff well, in SW. ¼ sec. 11, T. 4 S., R. 8 W., northeast of Waurika, Okla.

	Thickness.	Depth.
	Feet.	*Feet.*
Red bed	30	30
Shale, sandy	10	40
Shale, blue	30	70
Sand	5	75
Shale, mixed	45	120
Sulphur	1	121
Shale, blue	8	129
Sand, dry, show of gas	3	132

Partial log of Kauerauff well, in SW. ¼ sec. 11, T. 4 S., R. 8 W., northeast of Waurika, Okla.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale, blue	5	167
Rock	1	168
Shale, blue	10	178
Sand, gas	6	184
Shale	8	192
Gumbo	30	222
Shale, mixed brown and blue	28	250
Shale, blue	40	290
Shale, blue and black	44	334
Sand, show of oil	8	342
Shale, hard	1	343
Shale, blue	33	376
Shale, mixed blue and brown	40	416
Shale, dark brown	20	436
Shale, mixed blue and brown	50	486
Shale, dark blue	14	500
Limestone, soft	2	502
Shale, blue	19	521
Shell, limestone	1	522
Shale, blue	50	572
Shale, hard, dark blue	21	593
Shale, mixed blue and brown	20	613
Shale, blue and black	37	650
Limestone	1	651
Sand, show of gas	8	659
Shale, blue	29	688

Log of Byers Oil & Gas Co.'s well No. 1, 2 miles northeast of depot at Byers, Tex.

[Drilled in 1913.]

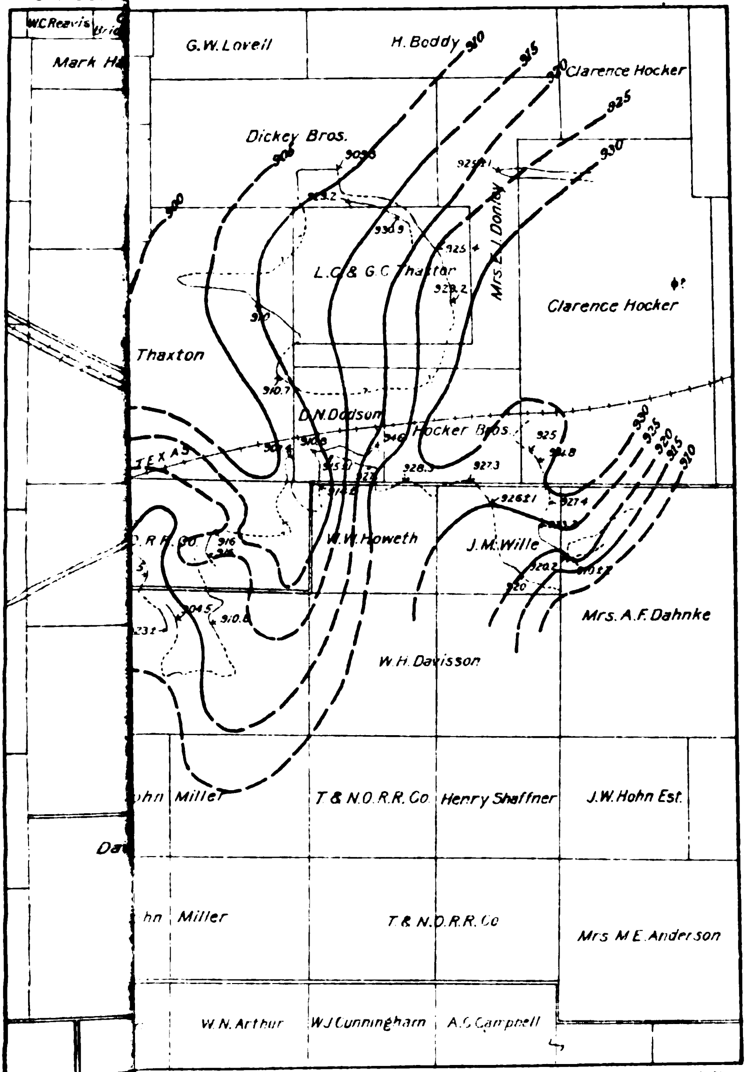
	Thickness.	Depth.
	Feet.	*Feet.*
Surface	30	30
Red rock	10	40
Shell	5	45
Red rock	230	275
Shale, blue	20	295
Red rock	55	350
Water sand	15	365
Red rock	65	430
Sand, salt water	7	437
Red rock	28	465
Shale, red and blue	30	495
Red rock	40	535
Shale, blue, shelly	10	545
Red rock	100	645
Shale, red and blue	5	650
Red rock	10	660
Shale, blue and red	27	687
Sand, salt water	8	695
Shale, blue and red	90	785
Sand, salt water	30	815
Red rock	30	845
Sand, salt water	30	875
Shale, blue	10	885
Sand, salt water	5	890
Red rock	5	895
Sand, salt water	15	910
Red rock	25	935
Shale, blue	60	995
Sand, salt water	15	1,010
Shale, blue	25	1,035
Sand, salt water	40	1,075
Shale, blue	10	1,085
Sand, salt water	60	1,145
Shale, blue	7	1,152
Red rock	8	1,160
Shale, blue and red	10	1,170
Red rock	20	1,190
Shale, blue	10	1,200
Sand, salt water	20	1,220

Log of Byers Oil & Gas Co.'s well No. 1, 2 miles northeast of depot at Byers, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Red rock	15	1,235
Shale, blue, shelly	20	1,255
Sand, dry	7	1,262
Shale, blue	15	1,277
Sand, salt water	8	1,285
Shale, blue and red	15	1,300
Shale, blue	15	1,315
Red rock	7	1,322
Sand, salt water	11	1,333
Red rock	9	1,342
Shell	5	1,347
Red rock	13	1,360
Shell	10	1,370
Red rock	15	1,385
Shale, blue	17	1,402
Sand, salt water	10	1,412
Red rock	8	1,420
Shale, blue and red	30	1,450
Shale, blue, shelly	20	1,470
Red rock	5	1,475
Shale, blue and red, very shelly	35	1,510
Shale, blue	20	1,530
Sand, salt water	10	1,540
Shale, blue	35	1,575
Sand, salt water	15	1,590
Red rock	5	1,595
Shale, blue	5	1,600
Sand, salt water	60	1,660
Shale, blue	5	1,665
Shell, hard	10	1,675
Sand, salt water	15	1,690
Shale, blue, very shelly	30	1,720
Red rock	15	1,735
Shale, blue	2	1,737
Sand, salt water	23	1,760
Shale, blue	56	1,816
Sand, salt water	4	1,820
Shale, blue	5	1,825
Shell	10	1,835
Shale, blue	5	1,840
Shell	5	1,845
Shale, blue	40	1,885
Sand, salt water	15	1,900
Shale, blue and red	7	1,907
Sand, salt water	3	1,910
Shale, blue	5	1,915
Shell	3	1,918
Shale, blue and red	4	1,922
Sand, salt water	3	1,925
Shale, blue	10	1,935
Shell, hard	3	1,938
Shale, blue	7	1,945
Shelly	10	1,955
Shale, sandy, blue	45	2,000
Sand, salt water	30	2,030
Shale, black (oily black)	5	2,035
Shale, sandy, blue	40	2,075
Sand, salt water	7	2,082
Shale, sandy, blue, and gas bubbles	178	2,260
Shale, blue	5	2,265
Shale, brown	5	2,270
Sand, salt water	5	2,275
Shale, blue	5	2,280

STRUCTURE IN THE VICINITY OF HENRIETTA.

The results of a stadia traverse of the outcrops in the vicinity of Henrietta made by H. M. Robinson are shown in Plate V. The general dip, amounting to about 40 feet to the mile, is to the north. The structure is, however, irregular, and at some places, as in the



Land
and

Shallow well, show of oil

TEXAS

southwest part of Henrietta and half a mile farther southwest, the strata are slightly uplifted, so that they form low domes. The facts that the domes are very low and that the strata south of them continue to rise rather steeply make them seem unpromising for oil or gas, and one 2,000-foot dry hole has been sunk on one dome. The other structural features of the area surveyed appear still more unpromising for gas or oil. The anticlines and domes, as well as the more irregular features, are so flat or low as apparently to be of no consequence. The district surveyed may be on the north limb of a broad, irregular anticline, for the general dip observed can not continue far to the south. In territory south of the region surveyed the dip must either swing to the east or to the west or the strata must come down again so as to form an anticline. The strata studied are shown in the following section, which crops out between Henrietta and Little Wichita River, to the north:

Section of rocks of Wichita formation exposed in north part of Henrietta, Tex.

	Feet.
Sandstone capping the hill on which Henrietta is built	15–25
Conglomerate, clay pebble, very lenticular, pebbles mostly less than half an inch	0–2
Sandstone, olive-gray, laminated	1–4
Conglomerate like bed above, but pebbles somewhat larger; weathers into large resistant blocks	0–4
Clay shale, brownish red	8–12
Sandstone, olive-gray, open textured, soft, cross laminated	8–10
Shale, red, and sandstone in irregularly arranged lenses	8–12
Sandstone, gray, soft, open textured, cross-bedded	8+
	60±

STRUCTURE IN THE VICINITY OF BENBROOK.

The general eastward dip of the Cretaceous strata between Fort Worth and Weatherford is modified at Benbrook by a terrace or an asymmetric anticline. The results of a reconnaissance survey of this feature are shown in figure 4. Apparently it plunges to the north, but its precise form was not determined. A cross section of the terrace may be seen from a Texas & Pacific Railway train, for along the south side of the valley up which this railroad passes through Benbrook there are fairly good exposures of a bench-making limestone belonging in the Goodland limestone of the Cretaceous system. In the bottom of the valley of Trinity River, 6 miles southwest of Benbrook, there is a water well which occasionally gives off gas bubbles. The terrace may be the cause of this gas seep. The general nature of the rocks exposed in this vicinity is shown in the following section:

Generalized section of rocks of Goodland limestone (Lower Cretaceous) exposed near Benbrook, Tex.

	Feet.
Limestone ("fence rock"), flaggy, few fossils; breaks into slabs suitable for building rough stone walls and hence before the days of barbed wire was used commonly for fences	20±
Limestone ("broken rock"), rather soft and thick bedded	20±
Limestone, hard and thick bedded	25±
Limestone ("cement rock") showing much solution and cementation	10±
Limestone ("wolf dirt"), earthy, weathers rapidly to brownish earth, which is called wolf dirt because it is easy digging for wolves and, on account of the hard overlying bed, is attractive to them for making dens	15±
Limestone ("shell rock") very fossiliferous	10±

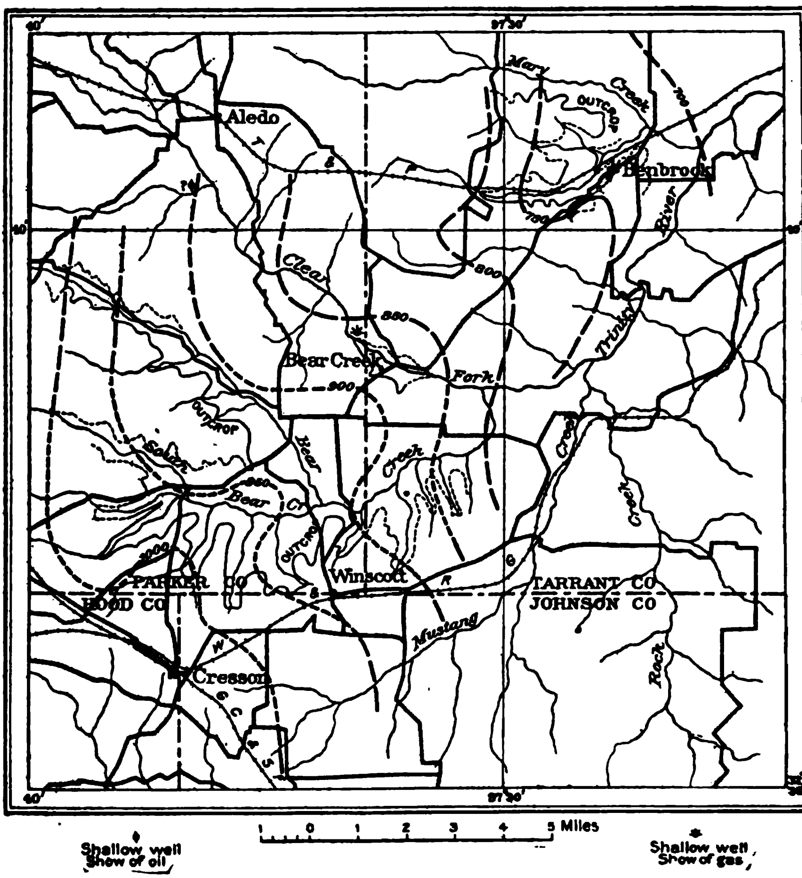


FIGURE 4.—Sketch map showing probable main features of geologic structure in the vicinity of Benbrook, Tex., based upon determinations of altitudes and dips by hand level and aneroid barometer. The thin lines show outcrops of certain limestone beds. Heavy lines are structure contours on the top of bench-making limestone. Dashed lines indicate doubt, the short dashes signifying greater doubt than the long dashes.

REPORTED INDICATIONS OF GAS.

A large number of places at which indications of gas were reported were examined. Among these was one on the Jackson farm, northwest of Dallas, where a peculiar welling up of very fluid mud was inspected and found to be due to causes other than pressure of natural gas. Several reported gas seeps also were visited and the gas of most of them was found to be marsh gas, which, though an excellent fuel, is in the places examined of surficial origin and does not indicate the presence of deep-seated and large pools of natural gas.

Several water wells from which bubbles of gas are reported to escape were visited, but natural gas was actually escaping from very few. Such seeps, unlike most of those of marsh gas at the surface, are likely to be true indicators of natural-gas pools. Puffs of natural gas are not at all uncommon in water wells in the region about Dallas and Fort Worth, but probably only a few of them are really near important pools. One of these gas seeps, which is about 8 miles a little west of north of Weatherford, is so copious that a structural survey of the surrounding area has been made by Mr. Robinson to see whether or not the geologic conditions, particularly the lay of the beds of rock, are favorable to the accumulation of a pool. The results of this survey show that the rocks have an almost uninterrupted northerly dip and are therefore not very favorable to the accumulation of a pool. The rocks at the surface here belong near the base of the Cretaceous, though the bottom of the well, 90 feet below the surface, probably does not reach the underlying Pennsylvanian.

Another class of indications considered worthy of examination are oil shows, for oil is very commonly associated with gas, but a great many of the oil seeps reported are in fact seeps of water containing iron hydroxide—a substance very similar to iron rust—which is common in marshy places. The iron makes an iridescent film on the surface of the water which to an unpracticed eye looks very much like oil. Iron hydroxide will not burn, however, and in a true oil seep it is generally possible to collect a sufficient amount of oil to show that it will burn.

Oil in water wells is generally worth careful study, for "the best sign of oil is a little oil." Small showings of oil and gas also are not at all rare in Clay County and elsewhere. Showings of oil are reported in several wells, about 70 feet deep, on the W. G. Smith place, at the northwest corner of the Charlton Thompson tract, 15 miles south-southwest of Henrietta. A brief inspection of the geology suggests that the structure near this place may be favorable to the accumulation of a pool. On the Calloway place, 4 miles southwest of Henrietta, a water well 60 feet deep showed a little oil and bubbled

with gas for several days. On the north edge of Henrietta, northeast of the standpipe, a well drilled for water is said to have bubbled with gas. On the Arthur farm, about 4 miles east of Henrietta, in the east half of block 11, oil is said to have ruined a water well. On the Harker farm, 3 miles east of Henrietta, a small showing of oil is said to have been found in a 200-foot well drilled as an oil test. It is rumored that small showings of oil were found in the very deep Halsell well, 6 miles west of Henrietta, and also in the three deep wells on the Raht farm, 20 miles south of Henrietta.

INCREASE OF MARKETED PRODUCTION BY CONSERVATION.

In recent years considerable thought has been given to the avoidance of waste in natural gas, with manifestly good results, but the losses are still great and are incurred at many stages in the recovery and marketing of gas. Gas pools are abandoned before they are exhausted, though, on account of the great elasticity of gas, their abandonment is not so regrettable as the failure to exhaust oil fields. The greatest loss arises from the fact that gas is harder to store and market than oil, and because of this and other facts, the desire among operators for oil wells is much greater than for gas wells. Hence drilling is commonly continued as long as possible in the search for oil, though in the meantime gas sands are tapped and much gas is allowed to escape into the air. Much gas is also allowed to go to waste while oil is being pumped. The yield of oil wells is more rapid, though shorter, from sands that contain considerable gas under high pressure—conditions that mean quick returns to the oil operator—but the question may be seriously raised whether he might not profit more by preserving the gas, which, as Johnson and Huntley[1] have recently pointed out, would make possible the recovery of a great deal more oil from each pool before it is abandoned.

Another kind of loss takes place within the well and consists of the escape of gas from an important gas sand up through the well to another sand, into which, under certain circumstances, it passes and becomes so widely disseminated that much or all of it is lost. This kind of loss occurs in closed wells in which sands above the gas sand are not cased off. In the Petrolia field the losses of this sort have not been great, for few wells have been left shut in for long periods. Most wells are cased with sufficient care to shut off higher sands, and there are not many or extensive higher sands which are capable of absorbing considerable quantities of gas.

Gas is also allowed to escape into the air for other reasons. Some wells, such as the famous Miller well, in the Petrolia field, have gone

[1] Johnson, R. H., and Huntley, L. G., The influence of the Cushing pool in the oil industry: Eng. Soc. Western Pennsylvania Proc., vol. 31, pp. 460–487, 1915.

wild, and many millions of cubic feet of gas have thus escaped. Other wells have been opened in order to reduce the head for one reason or another. Wells are commonly opened and allowed to blow in order to clean themselves, and some are opened to blow off accumulated salt water. Other losses are incurred by breaks and leaks in lines, uneconomical management, and other causes. The losses are of course comparatively greater in small fields that are without good marketing facilities than in large fields. In the Petrolia field it might be possible through conservation to increase the output by 10 or 20 per cent but probably not more. There can be little doubt that if gas were more valuable the ultimate total yield of the field would be considerably greater than it is likely to be under present conditions.

SUMMARY OF CONCLUSIONS.

The results of a geologic study of the gas resources available to Dallas and Fort Worth in the region north and west of those cities may be summarized as follows:

PETROLIA FIELD.

Original quantity of gas in the field.—The volume of pore space occupied by gas and the original rock pressure and also the relation between decline in pressure and percentage of depletion indicate that the original quantity of gas in the Petrolia field, measured at 8 ounces above atmospheric pressure, was about 120 billion cubic feet.

Ratio between percentage of depletion and amount marketed.—Statistics of production indicate that about 37 billion cubic feet of gas from the Petrolia field have been delivered to consumers. This quantity is about 75 per cent of the reduction of supply in the ground. The question whether or not this percentage should be larger is beyond the scope of this report, but it may be remarked that many gas fields show a greater waste.

Present capacity.—The Petrolia field as now drilled and equipped is capable of producing more gas per day than it has ever been called upon to produce. The limit of its daily capacity depends in part upon engineering considerations not discussed in this report, such as the handling of wells and pipe lines, but it is probably at least twice that of any demand which has been made upon it.

Capacity in near future of the field as now drilled.—The daily capacity of the wells in the field is steadily decreasing, and indeed the field as a whole is doubtless rapidly approaching its limit in rate of production. While the demands upon it have been steadily growing its capacity has been diminishing because of reduction of supply and pressure, and before many years have passed the supply will no longer meet the demand.

Capacity in distant future of the field as now drilled.—If no new gas wells were drilled the production would not only fall below the demand in a few years but in ten years the output would probably be too small to be worth transporting.

Increase of capacity through new wells to known sands in the proved field.—The capacity of the field may be kept up for a few years by new wells drilled to known sands within the proved field, but the present wells are rather evenly distributed and closely spaced, so that increase of output through new wells can not be great.

Increase of capacity through finding new sands in the proved field.—More gas can probably be found in some parts of the field by drilling deeper, for sands having favorable structure, texture, and stratigraphic and lithologic relations lie below the sands now producing. A few small gas-bearing lenses of sand lie above the producing sand, and though these lenses contain much less gas than the so-called deep sands they should not be overlooked.

Increase of capacity through finding new productive area adjoining the field.—The daily capacity of the field may be increased by new wells drilled outside the proved field to sands now producing. The structure of the field indicates that the actual area of the gas pool is probably twice that of the area now producing, though a part of the new area may yield oil instead of gas. The production can not, of course, be doubled by simply doubling the producing area, for gas has been slowly moving from the undrilled ground to the producing wells, so that throughout most if not all of the undrilled parts of the pool the original gas content and pressure in the sands have been reduced, though not so greatly reduced as in the developed part of the pool.

Increase in marketed supply through greater care in handling wells.—The depletion of the original supply of gas at Petrolia is evidently considerably greater than the quantity of gas marketed, the loss incidental to the production of oil being especially noteworthy. The output could be increased by handling the wells somewhat differently, but the work of properly caring for the natural supply must be left to the engineers.

Life of the field.—If all the gas at Petrolia could be delivered to consumers in Dallas and Fort Worth and other cities now drawing on the Petrolia supply it would probably last them, at the present rate of consumption, about 6½ years. If an estimate is made of the increase in consumption that will probably occur if the supply is adequate and no advance is made in the price, proper deduction being made for necessary losses in production and marketing, the estimate of 6½ years must be reduced to about 4 or 5, and if further allowance be made for unnecessary losses it must be reduced to 3 or 4 years, and a shortage will be felt in cold weather still sooner.

OTHER FIELDS.

Other discovered pools northwest and west of Dallas and Fort Worth, particularly those at Strawn and Moran, have noteworthy quantities of gas, though not so much as Petrolia, and these supplies would be available to the cities if the pools were near to each other or to the existing pipe lines.

Undiscovered pools of gas and oil undoubtedly exist in the area described in this report, and some of them will probably be large enough to warrant the building of individual pipe lines. If several of them were developed at once, however, sufficient gas would be made available to justify the construction of lines to groups of pools. The search for new pools must be pushed with vigor if the present output is to be maintained or increased.

GAS PROSPECTS SOUTH AND SOUTHEAST OF DALLAS.

By George Charlton Matson.

GEOGRAPHY.

In the autumn of 1915 the writer made detailed examinations of the geology and natural-gas resources at Mexia and Groesbeck, Tex., as well as a rapid reconnaissance of a narrow area extending from a point near Thornton northward nearly to Greenville. This area has a length of 110 miles and an average width of about 20 miles, and includes a belt of black clay lands that are locally covered by a few feet of sand and gravel. A more general reconnaissance was extended across the area from Greenville to Dallas and Fort Worth.

Gas has been developed in commercial quantities at Groesbeck, Mexia, Corsicana, and Chatfield, and oil has been exploited in the vicinity of Corsicana. The Mexia-Groesbeck gas field (Pl. VI, in pocket) is now supplying gas to Waco, Mart, Groesbeck, Mexia, Teague, Tehuacana, Wortham, Richland, and Corsicana. The Corsicana and Chatfield areas formerly supplied Corsicana but are not now being utilized. The areas comprised in these fields are approximately as follows: Mexia-Groesbeck, 11.8 square miles; Corsicana and Chatfield, 6 or 8 square miles.

The surface of this part of Texas has only a moderate relief, generally from 50 to 150 feet, though the extreme differences in elevation are somewhat greater. This surface is a product of the erosion of the underlying formations and of the local deposition of thin beds of sediments that form broad, level terraces along the streams. There are five distinct terraces, which are separated by more or less definite scarps having steep slopes. The original level surfaces of some of the higher and older terraces have been partly obliterated through erosion by small streams.

The terraces are of little importance in connection with oil and gas resources except where their level surfaces, formed by thin veneers of younger sediments, obscure the older formations and interfere with the geologist's determination of their character and structure. The terraces have a distinct economic bearing on the development of the region, however, because they furnish level areas suitable for agriculture and favorable for lines of transportation along easy gradients.

In general, the terraces have an indirect bearing on the development of oil and gas because of the character of the roads that cross them. Where clay soils are exposed the roads are exceptionally good during the dry season and very muddy and difficult to travel during wet weather. The sands of the terraces produce a condition just the reverse of that produced by the clays. They are much more difficult to traverse in dry than in wet weather, and in the Mexia-Groesbeck field especially they add to the cost of transporting machinery and materials required for drilling wells and constructing pipe lines. The larger cities in the region have recently constructed gravel or rock roads to facilitate transportation, and the network of these highways now makes travel easy between most of the principal cities and towns.

GEOLOGY.

The areas covered by the general examination are underlain by rocks of several geologic formations that are assigned to the Tertiary and Cretaceous systems. Only the lower part of the Tertiary extends into the region, and the formations represented are of no commercial importance. The formations belonging to the Upper Cretaceous series are the source of all the oil and gas that have been developed in commercial quantities in the area examined by the writer and they supply large quantities of oil and gas in Louisiana.

CRETACEOUS SYSTEM.

The Cretaceous system is divided into two major subdivisions, the lowermost known as the Comanche series, or Lower Cretaceous, the uppermost the Gulf series, or Upper Cretaceous. The distribution of these two series is shown in figure 1. The series are divided into formations, but it is impracticable to represent all these minor subdivisions on a map of so small a scale, and in this report some of the formations will be discussed in groups. The general sequence of the Cretaceous formations is as follows, the youngest formation being given at the top (see also Pl. VII):

Gulf series (Upper Cretaceous):
- Navarro formation, including Nacatoch sand member.
- Taylor marl.
- Austin chalk.
- Eagle Ford clay.
- Woodbine sand.

Comanche series (Lower Cretaceous):
- Washita group:
  - Denison formation.
  - Fort Worth limestone.
  - Preston formation.
- Fredericksburg group:
  - Edwards limestone.
  - Comanche Peak limestone. } Goodland limestone in northern part of area.
  - Walnut clay.

Comanche series (Lower Cretaceous)—Continued.
  Trinity group:
    Paluxy sand.
    Glen Rose limestone.
    Travis Peak sand.

COMANCHE SERIES (LOWER CRETACEOUS).

Trinity group.—The Trinity is the oldest and lowest group belonging to the Comanche series. In Oklahoma and northern Texas it consists of coarse light-gray or white quartz sands with local layers and lenses of gravel. Farther south, especially along Brazos River, marl and sandy limestone occur interbedded with the sands, and the Trinity becomes a group divisible into three formations—the Paluxy sand (at top), Glen Rose limestone, and Travis Peak sand. In general the upper part of the Trinity is finer grained and contains more marl and clay than the lower part. The Trinity group is generally rather loose or only slightly indurated and is referred to by the well drillers as pack sand, though at some places, especially where exposed, it is a hard sandstone.

Fredericksburg group.—The Fredericksburg group consists largely of chalky limestones, though its basal part includes more or less impure marl and calcareous clay, the Walnut clay.

Washita group.—The Washita group consists of alternate beds of marly clay and soft limestone. At some places the limestone predominates; at others the clay. Thin layers and lenses of sand occur, especially in the upper part of the group, and most of the limestones are impure, containing both sand and clay.

The materials range in color from dark gray near the base of the group to light gray near its top. On weathering they become yellow or red, the more pronounced colors being found in the upper formations, which contain a larger percentage of the iron compounds that form the coloring matter.

GULF SERIES (UPPER CRETACEOUS).

Woodbine sand.—The Woodbine sand consists of medium to fine-grained sand containing many layers and laminæ of clay. Thin beds and partings of lignite occur in this formation, and it contains fossil plants which, together with the lignite, indicate an abundant flora and form a probable source of gas and oil.

The sands composing the Woodbine formation are generally light gray and friable. Locally they are cemented into hard layers which the well drillers call "shells." At many places a large amount of shale and clay is interlaminated with the sands, but two or more

porous beds are usually found in the formation. These are good water-bearing beds and are apparently very persistent, because they are the source of water for many artesian wells.

Eagle Ford clay.—The Eagle Ford clay consists of light to dark-blue laminated clay, which is locally more or less calcareous and contains thin layers of very hard limestone. This limestone is generally earthy and at many places contains large numbers of shells of marine organisms. In northwestern Louisiana and the adjacent part of Texas there is a bed of sand at the top of the Eagle Ford clay that contains laminæ and layers of clay. This sand, however, which is known as the Blossom sand member, does not extend into the area covered by this report except in the vicinity of Cooper.

Austin chalk.—The Austin chalk consists of massive light-gray to white chalky limestones containing some hard layers. Locally thin beds of clay are found in this formation, especially at the east end of the area here discussed, in the vicinity of Terrell and Greenville. Farther east the lower part of the limestone is so impure that it loses its distinctive characteristics and becomes a marl—the Brownstown marl—and the overlying chalk is known as the Annona chalk.

Formations overlying the Austin chalk.—Above the Austin chalk are beds of dark-gray marl and shale and thin layers and lenses of sand. These beds have been divided into two formations—the Taylor marl, immediately overlying the chalk, and the Navarro formation. More recently Deussen[1] has used the name Nacatoch sand for one of the sand beds in this part of the Upper Cretaceous of eastern Texas, and in this report it is called the Nacatoch sand member of the Navarro formation. In general it is probable that the Taylor formation should be restricted to the more calcareous beds overlying the Austin chalk and that the clays, shales, and sands that overlie the Taylor should be placed in the Navarro formation. The shales above the Nacatoch may be the equivalent of the Arkadelphia clay of Arkansas and northeastern Texas, but detailed information for exact correlation is not yet available. Two fragments of valves of a fossil oyster were obtained from the gas sand of the Mackey well, near Mexia. These were identified as *Ostrea owenana* Shumard by L. W. Stephenson, who states that

> This species occurs in the Navarro formation in the vicinity of Corsicana and Chatfield, Tex., and in the Nacatoch sand of southwest Arkansas. The stratum from which this fossil was obtained in the Mackey well probably corresponds in age to and may be physically continuous with the Nacatoch sand.

[1] Deussen, Alexander, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Survey Water-Supply Paper 335, pl. 7, 1914.

Mr. Stephenson also says that the matrix is a glauconitic sand similar to the Nacatoch sand of Arkansas. He gives the following list of localities where this species of Ostrea has been found:

Nacatoch sand:

U. S. G. S. collection 7465. Cut of St. Louis & San Francisco Railroad, west of McNab station, Ark.

U. S. G. S. collection 7463. West bank of Little Missouri River at Nacatoch Bluff, Ark.

Navarro formation:

U. S. G. S. collection 7567. Chatfield road, 7 or 8 miles north of Corsicana, Navarro County, Tex. Fossils collected in the road and in a small branch just east of the road.

U. S. G. S. collection 763 (U. S. Nat. Mus. catalogue No. 29876). Near Corsicana, Navarro County, Tex. Collected by T. W. Stanton.

U. S. G. S. collection 762 (U. S. Nat. Mus. catalogue No. 21089). Near Chatfield, Navarro County, Tex. Collected by T. W. Stanton.

Navarro formation (Nacatoch sand member):

Mackey well No. 1 of Peoples Gas Co., 2 miles northwest of Mexia, Limestone County, Tex., at a depth of 785 feet. Matrix a gray glauconitic sand. Collected by G. C. Matson.

The Taylor marl consists of dark-gray calcareous clays containing more or less carbonaceous matter, interbedded with lighter-colored clays and marls. In general the formation contains a small percentage of very fine sand, which is distributed through the clays in the form of very thin laminæ. Rounded and oval calcareous concretions occur at many places and in different parts of the formation. These are the bowlders mentioned in the logs of the well drillers. After exposure to the weather the Taylor marl changes to a dark-gray or black calcareous clay that is very plastic and sticky when wet.

The Navarro formation, including the Nacatoch sand member, consists of dark-gray and black clays containing more or less calcium carbonate, interbedded with thin layers of fine sand. These sand beds include thin partings and lenses of clay. Some layers of calcareous marl occur throughout the formation, and at many places there are concretions similar to those found in the Taylor marl.

The Nacatoch sand is typical of the sands found in the Navarro formation and is therefore worthy of special mention. It is composed of light-gray quartz sand containing some grains of glauconite. It is fine textured and is locally cemented into firm sandstone, especially near the top, thus forming a cap rock for the gas sand. It ranges in thickness from 40 to slightly more than 65 feet and in places contains partings of shale 3 to 4 feet thick, or rarely 8 to 10 feet. This sand has been studied very carefully, and its texture and porosity are described in detail on pages 92–93.

TERTIARY SYSTEM.

EOCENE SERIES.

Rocks of Tertiary age rest on the uppermost Cretaceous formation and possibly overlap some of the older formations of the Upper Cretaceous series. These deposits are the oldest and lowermost of the Tertiary system and belong to the Eocene series.

Midway formation.—The oldest of the Eocene deposits—the Midway formation—rests upon the Cretaceous in eastern Texas. This formation lies at the surface in the Mexia-Groesbeck gas field and extends both northward and southward in a narrow belt on the east side of the boundary line between the Upper Cretaceous and the Eocene, as shown in figure 1. The Midway formation consists of clays and some layers of fine sands and sandy clays. When fresh these materials are blue or gray, but on exposure to the air they become yellow or black. From the vicinity of Corsicana southward beyond a line drawn eastward from Hearne a series of limestone beds occur in the Midway formation. These limestones may be seen on the east slope of Pisgah Ridge at Tehuacana, at Horn Hill, on the road from Hearne to Thornton, and at many other places. They are conspicuous at several points in the Mexia-Groesbeck gas field, the best exposures being at the Reunion ground and near Springfield. Their average thickness is about 40 feet and their maximum thickness about 60 feet. The limestones are gray where freshly exposed, but on weathering they become yellow or brown. When partly dissolved they become deeply pitted. Fossils are abundant in some beds of the limestone.

NATURAL GAS.

OCCURRENCE.

Practically all the rocks of the earth's crust contain crevices or pores, the presence of the crevices being obvious wherever hard rocks are exposed to view, but the aggregate volume of openings of this kind is small when compared with that of the minute openings called pores. The average porosity of rocks of different kinds has been carefully studied, and though it varies greatly it amounts to a large percentage of the total volume of all rocks except the most compact. Among the most porous rocks are sandstone and coarse shales, though many limestones are nearly as porous as some sandstones.

In the study of the occurrence of natural gas the pores of the fine-grained rocks, such as shale and clay, even where their aggregate volume is very large, are of little importance, because in general the

gas that occurs in the minute pores of these sediments is so widely diffused that it can not be readily recovered. The important reservoirs of natural gas are sands and sandstones, though in a few places, including some comparatively large areas in Ohio and Indiana, porous limestones have supplied large quantities of gas. The gas in the sands and sandstones and in the porous limestones fills the pores of the rock and is commonly under considerable pressure.

CAP ROCK.

The gas is confined by a relatively impervious formation (cap rock), which prevents its migration toward the surface. The material that most commonly forms a cap above gas sands is a bed of fine shale, though very fine grained sandstones serve the same purpose because the pores between the grains are small. This was illustrated by an examination of a portion of the cap rock from the Mexia-Groesbeck gas field, which, with an aggregate pore space of 34.4 per cent of the total volume of the sample, contained such minute individual openings that C. E. Van Orstrand, who made the examination, decided that with the presence of a small amount of liquid the great resistance offered to free movement of gas was sufficient to make the rock an efficient cap. Impervious beds below the gas sand are not everywhere required to confine the gas, for in many gas fields the downward migration of the gas is prevented by water.

PRESSURE.

The term rock pressure, as applied to natural gas, is commonly used to designate the pressure under which the gas occurs in the earth. It is determined by means of a gage placed on the gas well and read when the maximum pressure is attained after the well has been closed to prevent the escape of gas. In general the gas is associated with salt water, and the initial rock pressure in any well is approximately equal to the hydrostatic pressure of a column of water with a height equivalent to the depth of the well. It therefore varies with the depth of the gas sand below the surface.

The rock pressure represents the maximum closed pressure of a gas well, but determinations are also made by permitting the well to flow freely and measuring the pressure of the flowing gas. This is designated as open-flow pressure. After a well has been permitted to flow in the air for some time, it may be closed and the pressure read at intervals, usually at the expiration of succeeding minutes. This is called minute pressure.

The open-flow pressure is an index of the volume of the well, and tables have been constructed for the estimation of volume from

the open-flow pressure. Minute pressures are used for the same purpose, but it is necessary to know the exact diameter and depth of the well in order to estimate the amount of gas that enters the well from the sand between the intervals of reading the pressure.

It is sometimes assumed that a well which has a very high rock pressure must necessarily have a large volume or rate of flow, but this assumption is not warranted, though the rock pressure is one of the factors that controls the volume. It is also sometimes assumed that when gas wells have declined in volume and pressure they will recover if they are closed temporarily. This is true in so far as rock pressure is concerned, the recovery being due to the movement of water or oil or both into the gas sands, reducing the bulk of the gas and thereby increasing the pressure. It is not true that the total quantity of gas in the sand will be increased by this process, for it is simply a matter of concentration of the gas already in the sand. This process, however, by increasing the rock pressure increases the volume of the gas that can be obtained from the well and thus increases the open-flow pressure. The life of many wells may also be prolonged in this way.

ACCUMULATION.

Gas rises because it is of lighter gravity than the water in the porous formations, the most favorable place for its accumulation being the higher portions of an upward arch (anticline or dome) of the gas sand. The quantity of gas found in any anticline depends on the original quantity in the formation and the percentage of it that has accumulated in the anticline. Another favorable position for gas to accumulate is where the general inclination or dip of the gas sand is interrupted or lessened in a flat terrace. A slight upward bend in this terrace will form a low fold similar, in many respects, to an ordinary anticline. If the water, with which the gas was originally associated, is in motion this may facilitate the migration of the gas and its accumulation in the anticlines or domes. The mode of accumulation is shown graphically in figure 7 (p. 94).

STRUCTURE.

GENERAL CAUSES AND FORMS.

The attitude of the strata is usually discussed under the term structure. Most sedimentary beds were originally almost horizontal, but many have been disturbed by forces that altered their attitude, producing structural features that vary in character with the resistance of the beds and the intensity and direction of the forces causing the disturbance. The most common cause of such disturbance of the original attitude of deposits is pressure, by which the strata may be either bent or broken. The bending produces folds, and the breaking

and slipping of severed edges of strata along planes produce faults. The accompanying diagram (fig. 5) shows simple types of folds, the upward bends being known as anticlines and the downward as synclines.

Many types of folds and faults have been described, but most of them are not represented in the Mexia-Groesbeck gas field, and the reader who desires information about them is referred to textbooks on geology or reports dealing with the subjects of folding and faulting.

The steep dips of the gas sand in the Mexia-Groesbeck field show that the forces which produced the anticline were concentrated in a

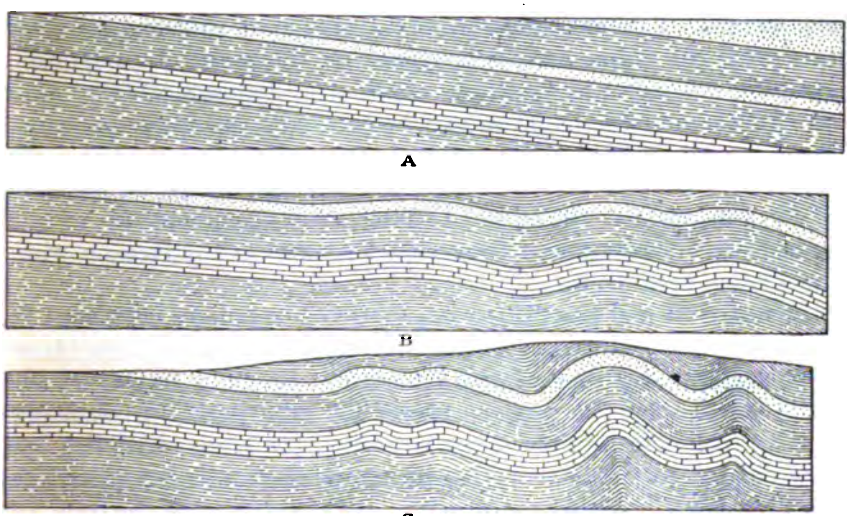


FIGURE 5.—Sections showing simple types of structure. A, Sedimentary beds with gentle dip; B, the same beds gently folded; C, the same beds more intensely folded.

small area that was subjected to vigorous disturbance. It is probable that this intense deformation of the strata was accompanied by some faulting, but no conclusive evidence of the existence of faults in the gas field was obtained. If there are faults in the field, they are doubtless of small throw and extent.

METHODS OF REPRESENTATION.

Structure may be represented diagrammatically, as in figure 5, or by means of contour lines, as in Plate VI. These lines are represented as connecting points, on the top or bottom of a stratum of rock, that lie at the same distance above or below a given horizontal plane, generally sea level. When contour lines are thus drawn, indicating every 10 feet, say, of difference in elevation, or any other definite

interval (called contour interval) that may be adopted for the whole map, it is possible, by noting the closeness and the direction of the contours, to interpret the character, the direction, and the pitch of the slope in any part of the bed that has been uplifted or warped out of a horizontal position. The refinement with which the minor warping can be shown depends on the amount and accuracy of the information available and the refinement in the contouring that can be based on it. The elevation of the stratum at any point in the contoured area may be determined by referring to the elevations indicated by the nearest contour line. Diagrams give a more graphic picture of structure than contours, but their usefulness is limited because they show structure only along certain lines across the area represented. Contours possess the advantage of showing the structure over the entire area represented on the map. In regions of complex folding and faulting, where it is impracticable to draw structural contours, diagrams may be necessary, but in regions where the rocks are only slightly deformed contour maps are more satisfactory. The reliability of the contouring depends on the adequacy of the information available. Usually some prominent bed of rock or some easily recognized formation is chosen as the base on which the contours are drawn.

In many oil and gas fields persistent coal beds have been used for the purpose of constructing contour maps, but in the Mexia-Groesbeck field the cap rock of the gas sand is the only formation that could be used for this purpose except the sand itself. Inasmuch as the cap rock is merely the upper portion of the sand, which has been consolidated to varying depths, its upper surface is considered the most trustworthy key to the structure. The contours on the structure map of the Mexia-Groesbeck field (Pl. VI, in pocket) are based on the top of the cap rock and show its depth below sea level. The contour map represents the key rock as it would appear if all overlying formations were removed. The position of the contours has been determined by subtracting the elevation of the surface at the well from the depth to the cap rock.

The degree of accuracy in drawing structure contours depends in part on the accuracy of measurement of the depth to the key rock, and in part on the number and distribution of the wells showing the depth to the key rock. In general, it is believed that the measurements used for the accompanying map are reasonably exact and that the wells are sufficiently numerous and distributed over enough of the territory to permit accurate contouring. In a portion of the field where information is lacking the structure has been represented by dotted lines drawn on the basis of surface observations on outcrops of limestone, together with the knowledge of the character and gen-

eral trend of the anticline that is shown by the contours. In order to show more clearly the structure of the Mexia-Groesbeck field a profile showing the elevation of the apex of the anticline has been included (fig. 6).

MEXIA-GROESBECK GAS FIELD.

LOCATION.

The Mexia-Groesbeck gas field is in the east-central part of Limestone County, Tex., where it occupies a long, narrow area, having an approximate length of 12¼ miles and an approximate width of 0.9 mile. The map of this field (Pl. VI, in pocket) shows the area that it occupies and its relation to the towns of Mexia and Groesbeck. The present developments are comprised in an area extending from a point near Mexia southward to Navasota River, and in another area extending from the south side of the river to a point a short distance southwest of Groesbeck. It is entirely probable that the actual distribution of gas is such as to join these fields through the strip about 0.9 mile wide that now lies between them.

CONSUMPTION OF GAS.

The present consumption of gas from this field amounts to more than 4,000,000 cubic feet a day, which is drawn from about 20 wells, but there are at present more than 40 wells in the field that are capable of supplying gas to pipe lines. In addition, several wells that are now in so bad a condition that they can not be utilized could probably be made to supply gas by removing the accumulated shale and sand.

PRODUCTION.

The total possible production from the Mexia-Groesbeck field has been determined by gaging all the wells that could be allowed to flow open for a long enough time, usually 45 minutes or more. A few wells were connected

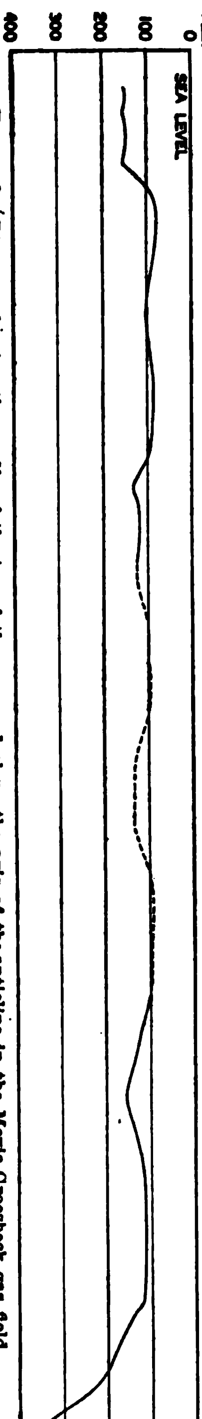


FIGURE 6.—Diagram showing the profile of the top of the gas sand along the axis of the anticline in the Mexia-Groesbeck gas field.

with pipe lines in such a way that it was impossible to open them without interfering with the consumption of the gas, and they were not gaged in this investigation; but reliable information concerning the volume of most of them was obtained from records of earlier gaging. In addition, some wells were found to be so badly clogged with shale and sand that gaging was impossible. The original volumes of these wells were ascertained from the most reliable sources, and after making due allowance for depreciation, an estimate was made of their possible present volumes, provided they were cleaned out and connected for use. The details of the methods of measurement and results are given in another section, and it is sufficient to say here that the present open-flow volume of this field is about 220,000,000 cubic feet a day.

HISTORY.

The beginning of active drilling in the vicinity of Mexia dates from the first operations by the Mexia Oil & Gas Co. under the active management of J. B. Smith. Ten wells were drilled before a successful dry gasser was obtained, and this well, drilled in 1912, made the first production in the field. Prior to the drilling of these wells gas had been known in a few shallow water wells west of the field and had been exploited in the vicinity of Corsicana. Wells showing considerable volumes of gas had also been drilled between Corsicana and Mexia, but salt water interfered with development.

After the first successful well was completed operations were much more active, with the result that seven successful wells had been drilled by July 25, 1913. Eight or nine other wells were completed before the end of 1913, and more than 30 were added to this number during 1914. The ratio of successful wells and dry holes may be judged from the examination of the map (Pl. VI) which shows the location of the wells and indicates their character.

During 1914 pipe lines were laid to connect the field with the larger towns, among them being Mexia, Groesbeck, Waco, Mart, and Corsicana; and these towns, together with some smaller communities, are still being supplied with gas from this field.

STRATA ENCOUNTERED IN DRILLING.

MIDWAY FORMATION.

The wells in the Mexia-Groesbeck gas field pass through the lower Eocene Midway formation and penetrate a portion of the Upper Cretaceous Navarro formation. The exact thickness of the Midway formation in the wells can not be determined with accuracy because the

descriptions of the materials encountered in drilling are not complete enough to enable a geologist to distinguish between the Midway and the Navarro. The Midway formation consists of clay, limestone, and sand that form the upper 50 to 200 feet recorded in the well logs. The limestone varies greatly in hardness and ranges in thickness from 40 to 60 feet. It is interbedded with clay and where it is soft it is often described as clay. Local hardening of the limestone has caused the abandonment of many wells that might have been successful if they had been drilled through the rock to the gas sand.

Layers of the limestone are exposed on eroded surfaces, and where the surface is level the successive layers form bands that are roughly parallel. Such layers show the strike of the beds, and two of them, known as the east and west ledges, happen to be so situated that nearly all the wells drilled between them have been successful. By following these ledges, which have the same trend as the structure, it has been possible to develop the gas field across the uplands both north and south of Navasota River, but some trouble was experienced south of the river because a layer of limestone lying stratigraphically higher than those north of the river is exposed west of Groesbeck. This limestone was erroneously thought to be the same as one of the ledges north of the river, and the mistake led to the drilling of two or three wells where the gas sand was so low on the anticline that it contained very little gas.

NAVARRO FORMATION.

The upper portion of the Navarro formation, which underlies the Midway, is composed of clays and shales with thin beds of sand and sandstone. It is in most places so easily penetrated with a rotary drill that a few wells in which no hard rock was encountered in the Midway formation were completed in two or three days. The clays and shale of the Navarro formation range in color from dark gray to black, except 20 to 60 feet of shale immediately overlying the gas sand, which is light gray.

The gas sand of the Mexia-Groesbeck field has been called the Nacatoch sand member of the Navarro formation, and in the general discussion of the geology (p. 80) the evidence is presented for the correlation of this sand with the Nacatoch sand of northwestern Louisiana and southwestern Arkansas. The Nacatoch sand of the Mexia-Groesbeck field consists of light-gray fine quartz sand with many dark grains of glauconite. The upper part of this sand is cemented into a hard sandstone which is known to the drillers as the cap rock. This cap rock is much denser than the gas sand and has a thickness ranging from 1 to 10 feet and averaging about 5 feet. Beneath the cap rock the sand is porous except where there are layers and lenses

of clay. That the clay forms a negligible portion of the Nacatoch sand is shown by its absence in 48 wells out of a total number of more than 50 wells. In the Mexia-Groesbeck field the Nacatoch sand has a maximum thickness of more than 65 feet and an average thickness, if the cap rock is not included, of more than 40 feet.

GAS-BEARING SAND.

AREA.

Measurements of the limits in depth of the gas-bearing sand are essential in order to estimate the area underlain by sand that will be productive. Several careful computations were made to determine to what depth the sand is filled with gas. Some of the wells in the north end of the field were still in dry sand at depths of slightly more than 200 feet below sea level, farther south salt water was encountered at about 198 feet below sea level, and in the south end of the field salt water was encountered at about 207 feet below sea level. In order to make a safe estimate the margin of the gas-bearing area was drawn at a depth of 200 feet below sea level, or, as the cap rock, upon which the contours are drawn, has an average thickness of 5 feet, at the 195-foot contour.

EFFECT OF CURVATURE ON THE AREA AND QUANTITY OF THE GAS SAND.

An examination of the map showing the structure of the Mexia-Groesbeck field (Pl. VI, in pocket) will show that the surface of the gas sand is not horizontal but is bent upward in the form of an anticline. In considering the productive area and the quantity of gas sand that might be expected to contain gas, it was thought that this curvature might have an important bearing on the results, and in order to determine whether the curvature was important E. L. McNair made computations based on profiles of the top of the sand across different portions of the anticlines, so selected that the maximum and minimum curvatures and the mean curvature might be included.

From the profiles made from these cross sections the actual rise was computed for 10 different grades, the maximum grade being 8 per cent and the minimum 0.8 per cent, with an average of about 3.7 per cent. For the maximum grade the increase in area of the gas-bearing sand on 1 square mile resulting from the upward slope of the strata is 0.64 per cent, which is equivalent to an increase of about 2 inches in thickness. For a 5 per cent rise the increase in area is only 0.25 per cent, which is equivalent to an increase of 0.8 inch in thickness. It is apparent that the curvature of the sand is a factor too small to make any appreciable difference in the results and need not be considered in computing the areas and volumes of

productive sand, and the computations here given are therefore based on the area that the sand would occupy if it were horizontal. Measurements of the area of sand included in the contour of 195 feet below the sea gave 4,094 acres of proved territory north of Navasota River and 2,360 acres south of the river, with an intermediate area of 1,124 acres unproved but probably gas bearing.

THICKNESS OF THE SAND.

Very few of the gas wells in the Mexia-Groesbeck field reach the base of the gas sand, and it is therefore difficult to determine the exact thickness of the sand. Many of the wells on the higher part of the anticline penetrate the sand to a depth of more than 20 feet, and oral reports have been given of thicknesses greater than 43 feet. Evidently, therefore, the thickness is considerably greater than is indicated in the gas wells. On the eastern margin of the field the Harden well encountered 40 feet of sand. The Munger Oil & Cotton Co.'s well, on the Hickman lease, showed the following section: Sand, 15 feet; gumbo, 10 feet; sand, 40 feet. One of the Stitt wells showed the following section: Sand, 15 feet; gumbo, 10 feet; sand, 50 feet. There is no reason to doubt that these beds maintain a similar thickness throughout the gas field, though variations from the sections given above are to be expected. Apparently the gumbo of the Hickman and Stitt wells is lenticular, because it was not encountered in the Harden well, and many of the gas wells that penetrated the sand to depths of more than 20 feet did not encounter gumbo. A moderate estimate of the average thickness of sand in the field, exclusive of the cap rock, is believed to be 40 feet.

QUANTITY OF THE GAS SAND.

The computations made to determine the area of producing gas sand in the Mexia-Groesbeck field gave a total of 7,568 acres—4,094 acres of developed territory north of Navasota River, 2,360 acres of developed territory south of the river, and 1,124 acres of undeveloped territory between the two tracts.

On the higher parts of the anticline in the Mexia-Groesbeck field the gas would occupy the pores in the entire thickness of the sand, and this condition would prevail down to a depth of 200 feet below sea level. As the gas-bearing sand has a thickness of 40 feet, the area in which all the sand contained gas would be inclosed by the 155-foot contour and would amount to 34 per cent of the developed area north of Navasota River, 50 per cent of the developed area south of the river, and 35 per cent of the undeveloped territory.

With a thickness of 40 feet, this portion of the field contains about half the gas-bearing sand in the developed areas and more

than half the gas-bearing sand in the undeveloped area. The gas would occupy only a portion of the total thickness of the sand in an area where the base of the sand was below the level of the salt water, which rises to 200 feet below sea level. The area containing gas-bearing sand would be bounded by the 195-foot contour, because, with an average thickness of 5 feet for the cap rock and a salt-water level at 200 feet below sea level, no gas in commercial quantities could be expected beyond that contour, though small pockets might be found where the bottom of the cap rock is uneven or where there are local flexures in the sand. The areas of gas sand included between the 155-foot and 195-foot contours are 66 per cent of the developed territory north of Navasota River, 50 per cent of the developed territory south of the river, and 65 per cent of the undeveloped territory. In these areas the thickness of the sand that lies above the level of salt water and contains gas ranges from practically nothing to 40 feet, with an average of 20 feet. With this thickness, the volume of the gas-bearing sand amounts to half the quantity in the developed areas and to less than half the quantity in the undeveloped area.

The total volume of the gas-bearing sand in the field would be 9,141,400,000 cubic feet, 85 per cent of which is in the developed territory and 15 per cent in the undeveloped territory.

PORE SPACE.

Samples of the gas sand from the Mexia-Groesbeck field were submitted to C. E. Van Orstrand, of the United States Geological Survey, to determine the amount of pore space they contained. His determinations showed from 16.6 to 34.2 per cent of pore space, with an average of 25.5 per cent, which would amount to 2,331,057,000 cubic feet. Only a small part of that amount belongs to the undeveloped area, the largest part of it being in the developed areas. There can be no doubt that the entire pore space of the gas sand was occupied by gas, because the pressure when the field was first developed, 276 pounds to the square inch, was sufficient to force the gas into even the most minute pores. It might be contended that the average porosity of the sand may not continue throughout the gas field, but such a contention would not agree with the generally uniform decline of pressure throughout the field, which indicates uniform porosity, for if there were obstacles to free movement of gas in the sand in the form of fine-grained portions of the sand or beds of shale there should be much greater variations in the pressure of wells that are close together because of unequal rates of decline. Moreover, the relatively large volume of the wells, even of those drilled only a few feet into the sand, indicates that the sand must

be very porous, because the volume depends largely on the rock pressure and the porosity of the sand, and with a present average rock pressure of 200 pounds to the square inch the average volume of 36 wells is over 5,000,000 cubic feet a day.

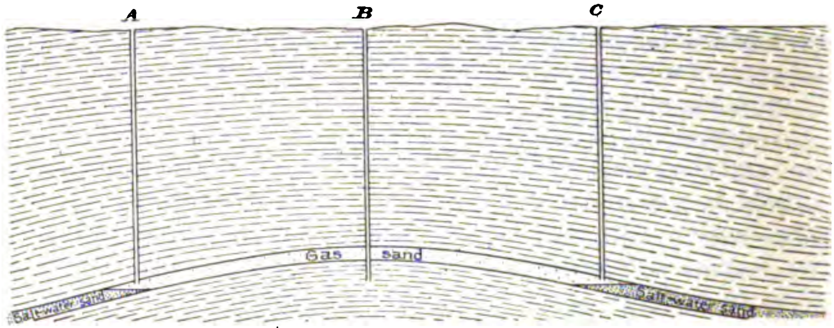
DISTRIBUTION OF THE WELLS.

Nearly 50 producing gas wells have been drilled in an area having an average length of about 16¼ miles and an average width of 0.8 mile. The locations of the wells in all except the south end of the field have been controlled chiefly by the requirements of the leases that contained drilling contracts and to a certain extent by the desire to offset wells of competing companies.

The developed portion of the field contains approximately 6,454 acres, and the number of wells actually drilled in this area is as great as would be required to drain the gas from the entire field, including the undeveloped territory. For comparison it may be stated that in some localities it has been held that only one gas well should be drilled to each 800 acres. It is doubtful, however, if any limiting area can be chosen that will be satisfactory for all gas fields, because the acreage required will vary with the structure of the gas field, the relation of the gas to the salt water, and the size of the pores and consequent freedom of movement of gas in the sand. An ideal arrangement of wells in the Mexia-Groesbeck field would be to space them at such distances from the sides of the gas-bearing area that they would have equal quantities of gas on each side. The distribution of the wells along the longer axis of the anticline should be controlled by the variations in the width of the fold, and the spacing between two adjacent wells should not be greater than one-half the average width of the fold in the vicinity of the wells. If spaced at greater intervals the wells will not drain all the gas from the sand. For a full utilization of the available supply the distance between any two wells should be equal to the shortest distance from either of the wells to the margin of the gas-producing area. This distance would be less than one-half the average width of the field near the wells, and where so spaced the wells might be expected to interfere with each other, but this interference would work no injury to the field and would merely diminish the daily yield of each well.

In the south end of the field the wells are distributed in such a way as to leave an interval of about half a mile between them. This interval is probably a little too great for the full utilization of the gas. Under the existing conditions all the gas in this field can be utilized only by controlling the yield of some of the wells that are too near the margin. This statement is best explained by reference to figure 7, *a*. To draw too heavily upon wells A and C will raise the level of the salt water and cut off from the main body of the gas a

portion of that which is contained in the sand farther down the dip. By checking the flow of these wells nearly all the gas in the sand at lower levels than those at which they penetrate it may be recovered. Well B, drawing from the sand at a point where there is no salt water, will have a much longer life and supply a much greater total quantity of gas because it will continue to flow after the salt water has migrated upward beyond wells A and C.



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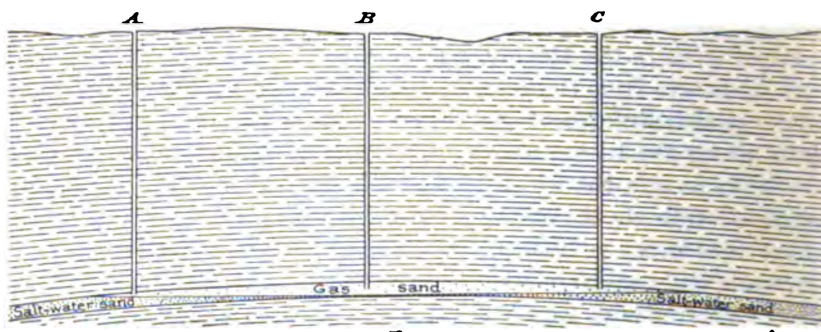

b

FIGURE 7.—Diagrams showing the occurrence of gas and salt water in different folds and their relation to the production of gas wells. *a*, Portion of the sand entirely filled with gas; *b*, salt water extending beneath the entire body of sand containing gas.

In those portions of the field where the sand lies so low that the conditions represented in figure 7, *b*, prevail the flow of gas from all the wells situated like those shown in the diagram will need to be controlled carefully in order to prevent the salt water from rising to the top of the sand in the vicinity of the wells before the total quantity of gas has been utilized.

DETERMINATIONS OF PRESSURE.

In determining the rock pressure of the wells in the Mexia-Groesbeck field three separate gages were used. These gages belonged to Supt. Anderson, of the Mexia Oil & Gas Co, Mr. F. G. Clapp, and Mr.

R. L. Underwood. The determinations with these gages did not agree very closely. Those made with the gages of Mr. Underwood and Supt. Anderson checked within 1 or 2 pounds of each other, but those made with Mr. Clapp's gage were from 5 to 12 pounds less than the pressures shown by the others. It was not practicable to have these gages tested by a machine company, and they were therefore checked with the Foxboro line gage of the Mexia Oil & Gas Co. The readings of the line gage and Mr. Clapp's gage showed a difference of 12 pounds at the time the test was made, and subsequent comparisons of Mr. Clapp's gage with those of Mr. Underwood and Supt. Anderson showed a similar difference. Corrections in accordance with these differences were applied to readings that were made with Mr. Clapp's gage alone.

The 37 wells used in determining the rock pressure for the field gave an average of 200 pounds to the square inch, but the variations between the wells in different portions of the field were so marked that it seems best to separate them into groups. The average pressure of 27 wells north of Navasota River was about 188 pounds to the square inch. The average of six wells just south of Navasota River was approximately 210 pounds, and the average of four wells just west of Groesbeck, belonging to the Robinson Oil & Gas Co., was about 270 pounds.

The original rock pressure of this field in July, 1913, after seven wells had been drilled, averaged about 276 pounds, and in October, 1915, one of the wells belonging to the Robinson Oil & Gas Co. showed a decline of only 2 pounds from this average, though some of the wells between the Robinson Oil & Gas Co.'s properties and Navasota River had declined in pressure below 200 pounds. On the north side of the Navasota very few wells showed pressures as high as 200 pounds at the time of gaging, and the maximum pressure determined was 213 pounds. The decline in rock pressure is shown in figure 8.

Rock pressures of wells in the Mexia-Groesbeck gas field.

[Pounds to the square inch.]

178	192	172	222	188	210
183	209	179	175	198	200
182	170	184	160	212	
276	197	206	170	188	
265	182	220	207	204	
272	173	200	187	213	
270	162	206	181	211	

In 37 wells the average rock pressure was 200 pounds to the square inch, though in the territory between the two developed areas the pressure should be nearly up to the initial 276 pounds per square

inch, and if wells were drilled in this undeveloped territory they would doubtless raise the average. Three additional wells could be drilled in the undeveloped territory near Navasota River that would probably have an average pressure nearly equal to the wells west of Groesbeck. With these additional wells the average pressure of the field would be about 205 pounds per square inch.

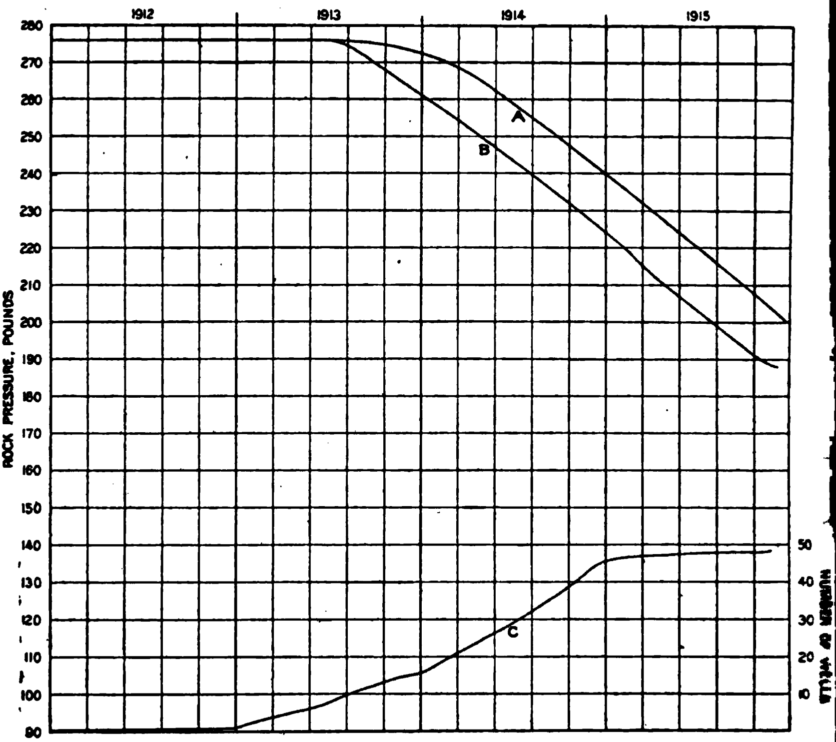

FIGURE 8.—Diagram showing the decline of rock pressure and the increase in the number of producing wells in the Mexia-Groesbeck gas field. A, Decline in whole field; B, decline in part of field north of Navasota River; C, increase in number of wells.

OPEN-FLOW VOLUMES OF THE WELLS.

In order to determine the capacity of the wells in the Mexia-Groesbeck field measurements were taken of the open-flow pressure of 36 representative wells, and the volumes were estimated by using tables issued for this purpose by the Oil Well Supply Co. These tables are copies of those published in volume 6 of the Ohio Geological Survey, pages 372 and 373, and represent careful determinations of the value of open-flow pressures in volume, stated in cubic feet daily. Nearly all the wells gaged to determine open-flow pressures were allowed to flow into the air for periods of 45 minutes or longer, and in many of them the pressure was gaged at intervals of 15 minutes from the time the wells were opened. One well, Webster

No. 2 of the Robinson Oil & Gas Co., was allowed to flow 23½ hours, and its pressure was determined at intervals for the purpose of constructing a curve showing the decline of pressure. This curve, together with the curve of another well in the south end of the field, is shown in the accompanying diagram (fig. 9). The list given below states the open-flow volumes of the wells at the expiration of 45 minutes after they were opened. Most of the figures represent actual

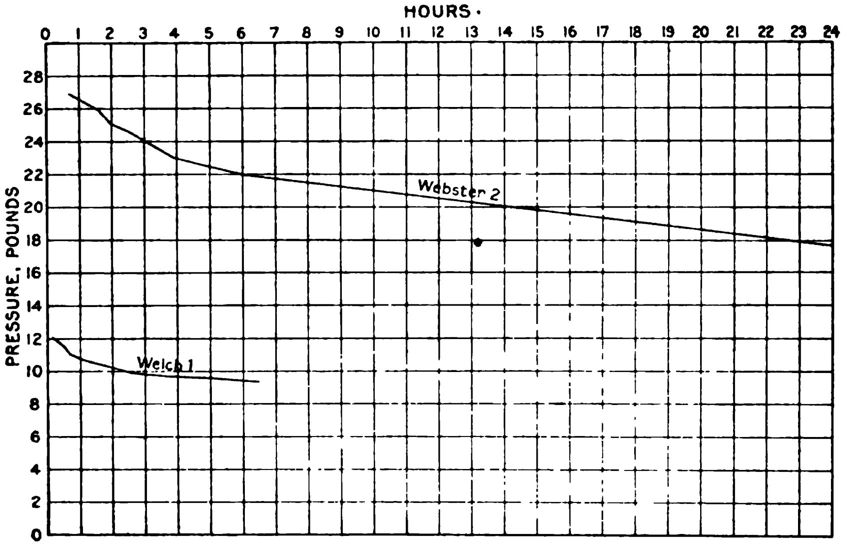

FIGURE 9.—Diagram showing the rate of decline in open-flow pressure of representative wells in the Mexia-Groesbeck gas field.

measurements, but the determinations for a few wells were made by interpolation or by prolongation of the curve obtained from readings for a shorter period. The determinations were based on a temperature of 50° F. for storage of the gas.

Open-flow volumes of wells in the Mexia-Groesbeck field, in cubic feet a day.

2,656,260	1,327,390	2,990,380	5,483,910
2,197,020	2,584,660	2,509,400	14,673,330
2,067,140	2,958,470	2,059,680	7,574,600
9,776,975	4,227,670	2,554,080	8,683,220
8,889,240	2,488,820	2,740,220	502,630
3,541,400	4,500,000	10,332,840	3,469,780
9,532,800	2,096,190	6,466,900	10,370,520
3,253,370	6,981,530	3,554,730	6,755,750
698,550	10,000,930	6,496,960	4,922,200

The total open flow for 36 wells at the expiration of 45 minutes was 181,919,545 cubic feet a day. To this total should be added about 40,000,000 cubic feet for wells not gaged. This volume could probably

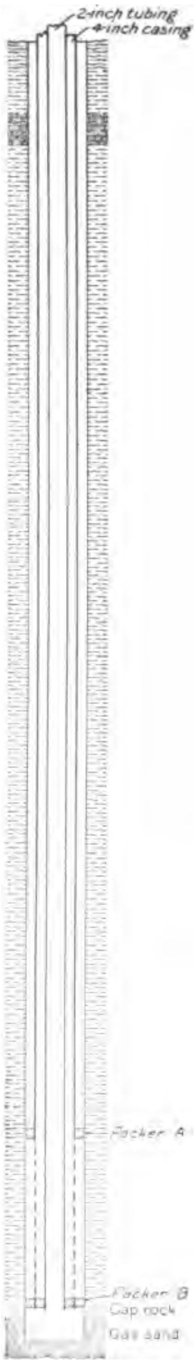

FIGURE 10.—Gas well in Mexia-Groesbeck field.

be increased 15,000,000 to 20,000,000 cubic feet by drilling enough wells to develop the territory between the producing areas, but the open flow of existing wells is about 220,000,000 cubic feet a day.

CONDITION OF THE WELLS.

The condition of the wells in the Mexia-Groesbeck gas field will seriously affect the amount of gas that can be obtained from them and the amount that can ultimately be obtained from the entire field. Most of the wells at the south end of the field have been cased to the cap rock, but the contact between the casing and the cap rock is not sufficiently tight to prevent the escape of gas around the outside of the casing. Cement has therefore been poured into the well around the casing to stop the escape of gas at the surface, but the efficacy of this method of cementing may be doubted, because not all the gas lost reaches the surface. In the northern part of the field the casings were set in the wells at some distance above the top of the gas sand. Many of the wells are finished with 4-inch casing set with the bottom some distance above the gas sand. (See fig. 10.) In some of these wells a packer is placed in position indicated by "Packer A." In order to prevent underground leakage of gas and caving of the sides of the hole the casings should be extended to the cap rock and the packer set at the point marked B. Some of these wells will probably need to be tubed with 2-inch pipe, with a packer (B) as shown in the diagram. The pressure of the gas in these wells declined rapidly before the construction of the principal pipe lines and the utilization of the gas in the cities that are now being supplied. This decline in pressure was due in part to the escape of gas into the strata above the cap rock, and the amount thus lost and the leakage from the gate valves and pipe lines amounted to about 24 per cent of all the gas originally in the field. This amount of gas was lost while the consumption was only about 4 per cent of the total supply of gas in the

field; or, stated in a different way, the waste has been about six times as great as consumption.

The conservation of gas after it is drawn from the wells is an engineering problem, because it depends upon prevention of leaks from pipe lines, valves, and other fittings, but the question of preventing loss underground is geological, being controlled in part by the character of the strata. The gas lost underground was in part taken up by the shale adjoining the lower portions of the wells, below the bottom of the casing, but in some wells some of the gas appears to have found its way upward around the casing into porous strata that contained some fresh water. In addition to the loss of gas, the gas entering the fresh-water strata displaced some of the water, which descended into the well and now appears in the form of water vapor or as moisture in the shale that is blown from the well. There are some indications that the rate of decline of pressure resulting from the loss of gas in the strata above the cap rock, at first rapid, is now gradually diminishing, probably because the openings in the strata near the well are becoming filled with gas.

It was at first believed that as the pressure of the field was lowered by consumption through pipe lines a portion of the gas that had entered the shales and sands above the cap rock might return to the well, but when the wells were gaged it was found that the lowering of the pressure resulting from the flow of gas into the air permitted the expansion of gas in the shales at so rapid a rate that fragments of shale were loosened from the wall of the well. Probably also some fresh water was forced down around the casing by gas in the upper water-bearing sands. It appears, therefore, that an attempt to recover the gas that has escaped into the formations above the cap rock is likely to be attended by clogging with shale and, in some wells, by flooding with fresh water. To avoid this danger it will be necessary to tube some of the wells with a pipe of smaller diameter, having a packer at the lower end, which should be firmly seated in the cap rock. This will necessarily result in diminishing the volume of gas that can be supplied from these wells, and most of the wells, being cased with 4-inch pipe, will need to be tubed with 2-inch pipe. This will decrease the volume of these wells to only about one-sixth of the volume supplied through the 4-inch casings, but it should prevent some of the wells from being clogged with shale or flooded with fresh water and in that way prolong their period of production.

AMOUNT OF GAS THAT CAN BE UTILIZED.

The total quantity of gas in the Mexia-Groesbeck field has been estimated at 2,331,057,000 cubic feet under a pressure of 200 pounds per square inch at the time the investigations for this report were made; but it is improbable that this gas can all be drawn from the

sand for commercial use. In the Cherryvale field, Kansas, wells with a pressure of 8 pounds to the square inch still had an average volume of 28,810 feet a day, and it is therefore apparent that wells may be utilized under a comparatively low pressure. However, computations made by G. F. Becker, of the United States Geological Survey, show that nearly 95 per cent of the gas will have been utilized when the pressure is reduced to 15 pounds, provided the total bulk of the sand occupied by the gas were as much as at the present time. This estimate is too small by an amount that will depend on the rate of utilization of the gas and the rate of movement of the water into the sand as the pressure is lowered. As both of these factors are unknown, it is not possible to determine in advance just what quantity of sand will be occupied by gas when the pressure has been lowered to 15 pounds to the square inch, and in order to avoid overestimating the amount of gas that can be utilized, it is assumed that the quantity of gas sand continues uniform.

LIFE OF THE FIELD.

Few problems present as great difficulties as are met in attempting to estimate the life of a gas field, because it is difficult to determine the amount of gas in the sand and almost impossible to estimate in advance the percentage of the available supply that will be utilized. The amount of loss, both by leakage and by leaving gas in the sand, can not be estimated in advance, because they depend upon the conditions controlling exploitation. Under the most favorable conditions, where the field is controlled and exploited as a unit and where care is exercised in the construction and maintenance of pipe lines and in the utilization of wells, the amount of gas recovered and marketed should be much higher than if the field is exploited in the usual way. In attempting to make comparisons between the Mexia-Groesbeck field and those of other localities, it was found that the conditions governing exploitation and the amount of gas originally present were so variable that it was not possible to reach satisfactory conclusions based on experiences in other fields. It would of course be possible to determine the average life of a large number of gas fields, but it is very doubtful if this would furnish any guide in arriving at a safe conclusion concerning the probable life of the Mexia-Groesbeck field, because of the diversity in occurrence, in amount of gas, methods of exploitation, and many other factors. The marked variations of different gas fields from the average that has been obtained show the impracticability of attempting to estimate the life of a gas field by comparison with other fields. Some fields have been found to be productive for more than 10 years, and others have been exhausted in a short time. For example, the Hogshooter field, in Oklahoma, was productive on a large scale for only a little more than two years.

For the reasons enumerated, it seems best to summarize the information concerning the amount of gas remaining, the percentage of the original supply that has already been withdrawn from the field, and the proportion of this amount that has been utilized by consumers. These facts, together with a knowledge of the history and condition of the field, should make it possible for those engaged in the future exploitation of the field to obtain the maximum amount of gas by reducing to a minimum the loss during exploitation.

The consumption of 10 to 12 per cent of the open-flow volume of the wells in the Mexia-Groesbeck field should be possible, provided the wells are tubed to the cap rock and kept in good condition. The total amount of this open flow will be reduced if the tubing is done with 2-inch pipe, and the capacity of the wells tubed will be only about one-sixth of their present capacity. The life of the field will depend in considerable measure on careful and systematic exploitation. If wells near the margin of the field are allowed to yield as freely as those on the higher portions of the sand, they will soon begin to blow salt water and will ultimately become flooded. The effect of heavy draft on marginal wells will be to bring the salt water that occurs beneath the gas into the wells, thereby interfering with the flow of gas. At the same time the upper portion of the gas sand a short distance from the well may still contain gas that under careful management should have been recovered. This condition is shown graphically in figure 7 (p. 94), and it can be avoided by controlling the flow of the wells near the margin of the field. The entrance of salt water into a well might be partly remedied by lowering its head by pumping, as it was found in some of the Kansas fields that a flow of 100,000 cubic feet of gas a day could be obtained from a salt-water well by this method, but the cost of pumping would probably be greater than the value of the gas recovered from most of the wells, and it will be better practice to delay the incursion of salt water by checking the flow of the marginal wells.

The Mexia-Groesbeck field, when examined in October, 1915, contained 2,331,057,000 cubic feet of gas, under a pressure of 200 pounds per square inch. This volume may be regarded as comparatively unimportant, but when it is considered that gas is consumed under a much lower pressure and has a much greater volume, it will be found that there is enough gas remaining in this field to be important. The gas now in the field, if placed in a container under a pressure of 15 pounds per square inch, would have a volume of 31,080,766,666 cubic feet. If the prospective consumption from this field by the cities now being supplied be estimated at 1,500,000,000 cubic feet a year, this amount of gas could be expected to last for more than 20 years, or if the computations made are regarded as too great by as much as 50 per cent it would still last more than 10 years, provided there was no loss from leakage. If the amount of

gas allowed to escape from wells and pipe lines continued to be as great as in the past, the field should supply the present demands for 5 to 7 years, and the percentage of the actual amount of gas from the sand that can be used will ultimately depend on the skill of the engineer in drawing it from the ground and transporting it to the market.

The present capacity of the wells, estimated at 10 per cent of the open-flow volume, would be about 22,000,000 cubic feet a day, but if the field is drawn upon at this rate without improving existing conditions of the wells many of them will continue to supply gas but a short time. If these wells should be improved and gas drawn from the wells at the rate of 22,000,000 cubic feet a day, the total volume in the field would last about 3¾ years, but again it is necessary to consider the ratio of consumption to waste, and the actual life of the field under such conditions will depend on this ratio.

ANALYSES.

The accompanying analyses of gas from the Mexia-Groesbeck field were made by G. A. Burrell in the laboratory of the Bureau of Mines at Pittsburgh, and an analysis of swamp gas collected near Natchez, Miss., is added for comparison. The samples were selected from different parts of the field and show the striking uniformity in the composition of the gas, which is nearly pure methane (CH_4), with small amounts of nitrogen (N) and carbon dioxide (CO_2).

Analysis No. 1 represents a sample taken from the Mexia Oil & Gas Co.'s Adamson well, near the north end of the gas field. Sample No. 2 was taken from the Central Texas Oil Co.'s Gamble well, between the Adamson well and Navasota River. The Posey well No. 1 of the Herring Oil & Gas Co., a short distance south of Navasota River, supplied sample No. 3. Sample No. 4 came from the Anglin well of the Robinson Oil & Gas Co., at the south end of the field. Sample No. 5 is the swamp gas from Natchez, Miss.

Analyses of gas.

[G. A. Burrell, analyst.]

	1	2	3	4	5
CO_2	0.6	0.2	0.7	Trace.	3.42
O_2	.0	.0	.0	0.0	.48
CH_4	98.4	98.3	98.1	98.5	81.12
N_2	1.0	1.5	1.2	1.5	14.98
	100.0	100.0	100.0	100.0	100.00
Specific gravity (air=1)	0.57	0.56	0.57	0.56	0.64
Heating value at 0° C. and 760 millimeters pressure, in British thermal units	1,047	1,047	1,045	1,052	884

A heating capacity of 1,047 British thermal units is much higher than that of the gas of the Petrolia field, described by Mr. Shaw on

page 41, which has a heating value of 755 British thermal units. Interpreted in quantities, this means that 1,000 cubic feet of gas from the Mexia-Groesbeck field has a heating value equivalent to about 1,390 cubic feet of gas from the Petrolia field. As shown by the table, the swamp gas represented by sample No. 5 has a somewhat higher heating value than the gas from the Petrolia field and a much lower value than that of the Mexia-Groesbeck field.

POSSIBILITY OF EXTENDING THE FIELD.

The southern limit of the Mexia-Groesbeck field has been outlined in the recent drilling by the Robinson Oil & Gas Co., but this does not mean that additional anticlines, having the same general trend, may not be found farther south. In fact, there seems to be a very good possibility for the occurrence of gas south of this field. This inference is drawn from the fact that a number of wells drilled at random have encountered small volumes of gas in the Nacatoch sand and from the additional fact that the general disturbances which produced the Mexia-Groesbeck anticline have been distributed over a much larger area than is represented in that anticline. The attempts of the writer to ascertain the extent of possible producing territory in that direction were hampered by the fact that the surface exposures are poor and by the lack of well-defined rock layers that can be traced over a large enough area to determine structure. It should be noted, however, that if more time could have been devoted to the work, some results might have been attained.

Some wildcat wells have been located beyond the southern limits of the field, and it is possible that they may furnish information concerning the structure, even though they may not be successful in finding commercial quantities of gas.

The general trend of the structure near the north end of the Mexia-Groesbeck field, together with some observations on the dip of shale beds, has suggested the possibility of extending the producing area toward the north. The most promising locality for such an extension is indicated on the structure map (Pl. VI, in pocket), and one or two wells should be sufficient to test the possibilities of obtaining gas in the area north of the field.

POSSIBLE INCREASE IN NUMBER OF GAS SANDS.

At the present time the Mexia-Groesbeck gas field derives its supply from a single sand, and no question has aroused more general interest than that concerning the possibility of finding additional sands at greater depths that may prove productive of either gas or oil. Consideration of the general section of the Upper Cretaceous formations shown in the diagram of the refinery well at Corsicana (Pl. VII) warrants the conclusion that there is a probability of finding

additional sands at greater depth. The question whether or not the sands will be productive is one that can not be answered except by drilling, though there seems to be an excellent chance that some of them will yield either gas or oil or both.

In discussing the geology it was noted that the characteristic fossils of the Nacatoch sand member of the Navarro formation are found at the surface at Corsicana and in the gas sand at Mexia. This leads to the conclusion that the surface formations at Corsicana are the substantial equivalents of those that would be found just below the gas-bearing sand at Mexia and Groesbeck. In the refinery well at Corsicana the gas sand was encountered at a depth of 1,075 to 1,095 feet and the oil sand between 1,205 and 1,215 feet. These sands may possibly be represented in the Mexia-Groesbeck field, and although their exact depth there can not be stated with accuracy, they should be expected between the gas sand of that field and the Austin chalk. If the beds at these horizons should prove to be barren, additional sands will be found at still greater depths. The Woodbine sand was encountered in the refinery well at Corsicana at a depth of 2,381 to 2,436 feet, and another porous sand at 2,444 to 2,484 feet. If a well drilled to test the lower sands should prove unsuccessful above the Austin chalk, it might be well to continue to these deeper sands in order to determine whether they are oil or gas bearing in the Mexia-Groesbeck field. In spite of the fact that these beds contain potable water at Corsicana, it is worth while to test them for oil and gas in the Mexia-Groesbeck field, where the structure is exceptionally favorable for the accumulation of oil and gas. The best place to locate a well to test the deep sands in the Mexia-Groesbeck field would be where the upper gas sand is high. Preference should therefore be given to the areas where this sand rises nearest to sea level, as shown by the contours on Plate VI (in pocket).

SUMMARY.

Of the area examined east and southeast of Dallas only the Mexia-Groesbeck field can be regarded as capable of producing enough gas to be of importance to a large city, and the value of this field depends very largely upon the elimination of waste in the production and marketing of the gas. The total volume of gas in October, 1915, has been estimated at 31,080,766,666 cubic feet, under a pressure of 15 pounds per square inch, the approximate pressure of consumption. If marketed at a rate of 1,500,000,000 cubic feet per year, the probable average consumption from existing pipe lines, the estimated life of that field, provided there is no waste, would be a minimum of 10 years and a maximum of 20 years; if marketed at the rate of 22,000,000 cubic feet per day, the capacity of the existing wells, the amount of gas in the field should be great

enough to last about three and three-fourths years, though before the expiration of the period the existing wells would need to be supplemented by others in the undeveloped territory, and in order to transport the gas to greater distances than the length of the present pipe lines it would be necessary to install compressors. It is possible that the Mexia-Groesbeck field may be extended toward the north and that new fields of similar character may be found both to the north and south of the existing field. An area 10 to 20 miles wide extending from Baileyville northeastward to the vicinity of Greenville and Cooper is regarded as worthy of more detailed geologic examination and prospecting with the drill, with the expectation of finding other fields similar to the Mexia-Groesbeck field. It is probable that new producing sands will be found in this pool, and some of them may have a greater capacity than the sand that has already been developed.

WELL LOGS.

Logs of wells furnished by the Mexia Oil & Gas Co.

Pittman well No. 26.

[Driller, S. T. Sturdevant. 581 feet of 6-inch casing, with 4-inch liner and tubing; concrete between casing and liner and outside of casing.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface soil and clay	55	55
Water sand	7	62
Soft water rock	4	66
Blue water sand with white shells	102	168
Black shale with streaks of gas sand	32	200
Gumbo; some 4 to 6 foot streaks of sand; some gas	50	250
Gumbo with layers of sand and bowlders, streaked	65	315
Tough gumbo	63	378
Shale	22	400
Gumbo	20	420
White "gippy" gumbo, very hard	10	430
Hard black slate	20	450
Tough gumbo	30	480
Slate	50	530
Gumbo	20	550
Loose blue shale; petroleum odor	15	565
Tough gumbo	35	600
Blue shale	47	617
Gumbo	8	655
Gray shale	8	663
White gumbo and gray shale	12	675
Hard cap	4	679
Sand and gumbo, streaked	13	692

Kimble well No. 24.

[Driller, S. T. Sturdevant. 33 feet 9 inches of 6-inch casing; 612 feet of 4-inch casing.]

Sand	32	32
Rock and bowlders	8	40
Blue sand	20	60
Shale and gravel	25	85
Black shale	50	135
Hard black slate	15	150
Gray or blue sandy shale	105	255
Black shale	345	600
Gumbo	15	615
Gray shale	25	640
White shale	10	650
Cap rock (porous sand)	6	656
Sand	11	667
Porous rock, second cap	8	675

Logs of wells furnished by R. L. Underwood.

Bates well No. 1.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface	8	8
Lime rock	165	173
Black shale	50	223
Gumbo	40	263
Gray shale	70	333
Gumbo	20	353
Gray shale	100	453
Gumbo	80	533
Gray shale and sand	150	683
Gumbo	40	723
Gray shale and some sand	100	823
Gumbo	20	843
Light shale and sand	52	895
Cap rock	3	898
Gas sand (gas at 900 feet)	5	903
Salt water at		912

B. B. Barron well No. 1.

Rock	235	295
Shale	540	835
Rock and sand (show of gas at 930 feet)	95	930
Shale	90	1,020
Rock	2	1,022
Shale	228	1,250
Rock	3	1,253
Shale	167	1,420
Rock	1	1,421
Shale	279	1,700
Sand (show of gas)	220	1,920
Shale and gumbo	80	2,000

Logs of wells furnished by T. F. Smith.

Louise Gamble well No. 1.

[Drilled in 1914. Wall, packer. 658 feet of 6-inch casing; 657 feet of 4-inch casing.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface sand	4	4
Yellow clay	4	8
Blue rock	8	16
Blue shale	280	296
Shale rock	7	303
Blue shale	114	417
Shale and gumbo	34	451
Gumbo	47	498
Blue shale	95	593
Gray shale	60	653
White shale	4	657
Cap rock	8	665
Gas sand	22	687

Joe Kennedy well No. 2.

[Drilled in 1914.]

Soil sand	4	4
Joint clay	47	51
Blue shale	348	399
Gumbo	44	443
Blue shale	160	603
Gray shale	33	636
White shale	4	640
Cap rock	7	647
Gas sand	23	670

Logs of wells furnished by T. F. Smith—Continued.

A. G. Manning well No. 1.

[Drilled in 1914. 20 feet of 6-inch casing; 735 feet of 6-inch casing.]

	Thickness.	Depth
	Feet.	*Feet.*
Soil sand	3	3
Yellow clay	17	20
Lime rock	27	47
Water sand	3	50
Lime rock	84	134
Packed sand	30	164
Lime rock	11	175
Packed sand	11	186
Lime rock	12	198
Packed sand	54	252
Blue shale	340	592
Gumbo	45	637
Blue shale	10	647
Gray shale	80	727
White shale	11	738
Cap rock	3	741
Gas sand	11	752

Mackey well No. 2.

Surface soil	4	4
Yellow clay	33	37
Black shale	600	637
White shale	41	678
Cap rock	4	682
Gas sand	8	690

William Stevens well No. 2.

[Drilled in 1914.]

Surface sand	3	3
Lime rock	16	19
Packed sand	8	27
Lime rock	14	41
Packed sand	42	83
Black shale	180	263
Gumbo	37	300
Black shale	95	395
Gumbo	185	580
Blue shale	60	640
Light shale	48	688
Cap rock	1	689
Sand	11	700
Salt water.		

W. H. Hill well No. 1.

[Drilled in 1914.]

Surface sand	4	4
Joint clay	42	46
Blue shale	280	326
Lime rock	38	364
Packed sand	40	404
Lime rock	3	407
Packed sand	12	419
Blue shale	95	514
Gumbo	85	599
Blue shale	90	689
White shale	13	702
Cap rock	8	710
Gas sand	12	722

Logs of wells furnished by T. F. Smith—Continued.

W. H. Hill well No. 2.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface sand	3	3
Joint clay	16	19
Rock and sand	184	203
Blue shale	74	277
Lime rock	30	307
Blue shale	27	334
Gumbo	195	529
Blue shale	104	633
Light shale	85	718
Cap rock	2	720
Sand	12	732
Salt water.		

J. B. Best well No. 1.

Surface	4	4
Joint clay	24	28
Lime rock	174	202
Packed sand	30	232
Black shale	190	422
Gumbo	85	507
Black shale	118	625
White shale	80	705
Cap rock	1	706
Sand	4	710
Salt water.		

Joe Kennedy well No. 3.

Surface sand	1	1
Joint clay	65	66
Blue shale	288	354
Gumbo and shale	27	381
Gumbo	85	466
Blue shale	127	593
Gray shale	67	660
White shale	5	665
Cap rock	8	673
Gas sand	20	693

A. E. Bertherson well No. 2.

[Drilled in 1914.]

Surface sand	3	3
Yellow clay	24	27
Lime rock	124	151
Packed sand and rocks	90	241
Blue shale	240	481
Gumbo	40	521
Blue shale	153	674
Light shale	48	722
Cap rock	7	729
Gas sand	21	750

A. E. Bertherson well No. 3.

[Drilled in 1914.]

Surface sand	4	4
Yellow clay	19	23
Lime rock	131	154
Lime rock and packed sand	94	248
Blue shale	245	493
Gumbo	120	613
Gray shale	45	658
White shale	41	699
Cap rock	24	723
Gas sand	24	747

Logs of wells furnished by T. F. Smith—Continued.

A. E. Bertherson well No. 4.

[Drilled in 1914.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface soil	4	4
Yellow clay	32	36
Lime rock	90	126
Lime rock and packed sand	127	253
Blue shale	160	413
Lime rock	8	421
Blue shale	84	505
Gumbo	70	575
Gray shale	92	667
White shale	37	704
Cap rock	12	716
Gas sand	22	738

Stewart well No. 1.

Brown surface sand	3	3
Yellow clay	28	31
Lime rock	8	39
Water sand	12	51
Lime rock	4	55
Sand rock	12	67
Blue shale	92	159
Gumbo	74	233
Gumbo and shale	278	511
Gray shale	124	635
Light shale	34	669
Cap rock	1	670
Gas sand	6	676
Salt water.		

Joe Kennedy well No. 1.

Brown surface sand	3	3
Joint clay	45	48
Blue shale	184	232
Shell rock	3	235
Blue shale	10	245
Shale rock	7	252
Blue shale	227	479
Gumbo and shale	30	509
Gumbo	60	569
Light shale	64	633
White shale	28	661
Cap rock	12	673
Gas sand	18	691

William Stevens well No. 1.

[Drilled in 1914.]

Surface sand	1	1
Joint clay	18	19
Sand rock	3	22
Blue shale	15	37
Sand rock	8	45
Blue shale	170	215
Gumbo and shale	140	355
Gumbo	200	555
Blue shale	35	590
Light gray shale	87	677
White shale	21	698
Cap rock	2	700
Gas sand	20	720

Logs of wells furnished by T. F. Smith—Continued.

R. H. Lyle well No. 1.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface sand	8	8
Joint clay	32	40
Sand rock	8	48
Water sand	16	64
Lime rock	12	6
Packed sand	56	132
Blue shale	345	477
Gumbo	60	537
Blue shale	35	572
Gumbo	10	582
Blue shale	20	602
Light shale	85	687
White shale	28	715
Cap rock	3	718
Gas sand	8	726

R. H. Lyle well.

[Drilled in 1914.]

	Thickness.	Depth.
Surface sand	6	6
Joint clay	45	51
Blue shale	375	426
Gumbo	40	466
Blue shale	165	631
Light shale	64	695
White shale	3	698
Cap rock	3	701
Gas sand	10	711

Mackey well No. 1.

	Thickness.	Depth.
Surface soil	3	3
Yellow clay	44	47
Black shale	173	220
Lime rock	38	258
Black shale	120	378
Gumbo	170	548
Gray shale	40	588
Black shale	212	800
No sand.		

AREA COVERED BY A GENERAL RECONNAISSANCE.

PRINCIPAL FEATURES.

A general reconnaissance was extended from the vicinity of Thornton northward a distance of 120 miles to Cash, and covered a strip of territory from 10 to 20 miles in width. At many places in this area small quantities of gas have been found associated with salt water, and gas has been developed in commercial quantities at Mexia, Groesbeck, Corsicana, and Chatfield. In addition, a large quantity of oil has been obtained in the vicinity of Corsicana. The presence of the gas indicates that the areas are underlain by formations that may supply gas or oil wherever the structure is favorable for the accumulation of these substances. The surface exposures are so poor that search for such structure must be confined very largely to the collection of data from wells. Information obtained at Wortham, Currie, Corsicana, Mabank, and Cash shows that there has been more

or less deformation of the strata throughout a large part of the area examined. The evidence indicates that the former southeasterly dip of the formations in this territory is in many places lessened and at some places even reversed, the dip being toward the northwest. The presence of this area of deformation leads to the conclusion that it probably contains other undiscovered structures similar to those at Mexia, Groesbeck, Corsicana, and Chatfield. It is inferred that these structures probably have small areas, and their discovery will depend very largely on drilling wildcat wells, with such assistance as can be rendered by a geologic study of the scattered surface exposures and the logs of wildcat wells that have already been drilled.

WORTHAM.

One of the first discoveries of gas south of Corsicana was made at Wortham, about 7 or 8 miles north of Mexia. The discovery well was owned by the city and was within the corporate limits. It had a very large flow of gas and sprayed enough oil to stain the buildings in the vicinity. The log of this well, furnished by Mr. C. L. Witherspoon, shows the character of the formations penetrated.

Log of the city well at Wortham.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale and gumbo	......	1,120
Hard gumbo and shale	80	1,200
Hard sand	30	1,230
Gumbo	20	1,250
Rock	4	1,254
White sand	5	1,259
Rock	½	1,259½
Oil and gas sand	21	1,280

Another well drilled near Wortham, on the Speed lease, furnishes a section to a greater depth than the city well.

Log of Speed well, near Wortham.

	Thickness.	Depth.
	Feet.	*Feet.*
No record	......	800
Shale and gumbo, with some sand	665	1,255
Hard sand, with some shale	55	1,510
Soft shale	150	1,660
Hard sand rock	80	1,740
Soft shale	490	2,230
Lime rock	18	2,248

The hard sand rock at 660 to 740 feet contained enough gas to blaze above the floor of the derrick when ignited. The lime rock encountered at the bottom of the well is apparently the Austin chalk, and

this log, together with that of the city well, shows that there are at least two sands in the shales and clays overlying the Austin chalk.

The city well at Wortham was completed May 12, 1912, and while the casing was being withdrawn it blew out with so large a volume of gas that it could not be controlled. It continued to blow gas with a spray of oil for a week, when it finally became choked with sand. The driller asserts that it was the largest gas well that was ever drilled in Texas. The unusual volume of gas obtained from this well caused considerable excitement and led to the drilling of a number of others. One well about 50 feet from the city well was drilled to a greater depth without encountering either gas or oil. Another well about 50 yards east of the discovery well encountered enough oil at a depth of about 1,180 feet to permit the pumping of about one barrel a day. A well about 50 yards south of the discovery well, with a depth of about 1,220 feet, had a flow of gas estimated at 4,000,000 cubic feet a day, but this flow continued only a short time until the well was flooded with salt water.

According to the reports of some of the citizens, more than 30 wells were drilled in the vicinity of the town, but none of the others encountered enough gas or oil to be of any value. Apparently, the structure conditions in this vicinity are unfavorable for the accumulation of any large quantity of either gas or oil, though they may be found in small areas, such as those around the city well and the other productive wells near by.

CURRIE.

The accompanying diagram (fig. 11) shows the distribution of a few wells in the vicinity of Currie. These wells are of considerable interest because some of them had large volumes of gas when they were first drilled, and at least one of them was capable of producing a small amount of oil. The Henry Swink well (No. 1) is still bubbling considerable gas four years after it was drilled and makes a better showing than any of the other wells in the vicinity of Currie. The depth of the gas sand in this well could not be learned.

Well No. 2 is now being drilled to test the capacity of the shallow oil sand.

Well No. 3, on the Quinby farm, encountered gas sand at a depth of 419 feet below sea level. This well now shows a small amount of gas bubbling through salt water. A thin bed of sand was encountered at a depth of 300 feet, below a thick layer of limestone.

Another well (No. 4) that was drilled three-fourths of a mile north of Currie, on the Hillburn farm, encountered oil in sand 5 feet thick at a depth of 360 feet. Beneath the oil sand was 33 feet of lime rock,

and the gas sand was encountered at 882 feet and extended to a depth of 904 feet. The log of this well from 904 feet down is as follows:

Log of lower part of Hillburn well near Currie.

	Thickness.	Depth.
	Feet.	*Feet.*
Shale and gumbo	33	937
Salt-water sand	20	957
Sand rock	4	961
Pack sand with some shale	159	1,120
Shale and gumbo	380	1,500

A little high-gravity oil is now flowing from this well and is accompanied by a few bubbles of gas and a large amount of alkaline water. The gas comes from the sand at a depth of 542 feet below sea level, and the oil is reported to be from the sand immediately overlying the limestone.

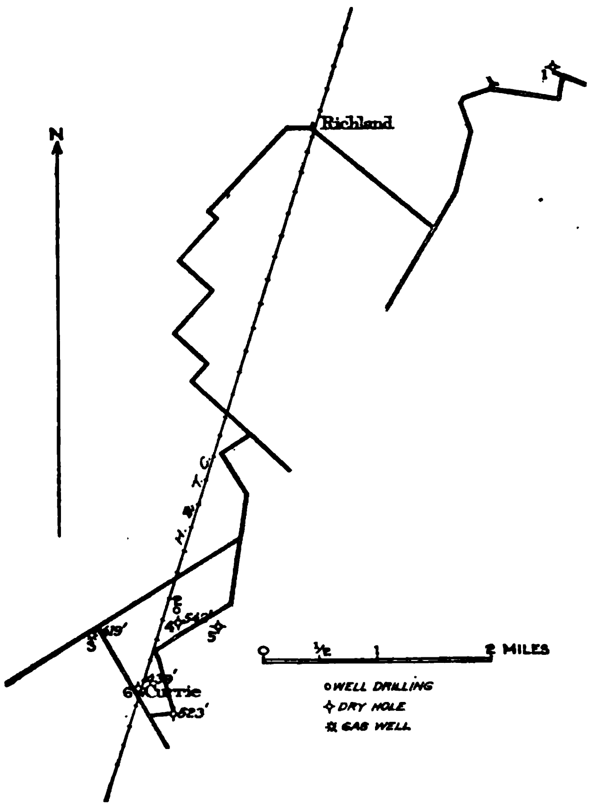

FIGURE 11.—Diagram showing the relations of wells drilled at Currie.

About half a mile east of the Hillburn well gas was encountered in a well drilled on the Brinson farm (No. 5). The exact depth to the gas-bearing sand at that point could not be learned, and according to the most reliable information the flow of gas lasted only a few hours.

The well on the Frank Wright farm (No. 6), near the Houston & Texas Central Railroad at Currie, is said to have yielded sufficient

gas to be utilized, but within a few days the flow of salt water became so large that the well had to be abandoned. The log of this well is as follows:

Log of Frank Wright well, Currie.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand and clay	70	70
Shale	290	360
Hard lime rock	40	400
Shale with a few bowlders	450	850
Gas sand	15	865
Gumbo	20	885
Salt water sand	20	905

The varying depths to the gas sand in the vicinity of Currie suggest that the sand, if it is continuous, must have undergone a marked deformation, probably accompanied by faulting on a large enough scale to destroy its continuity. As an alternative explanation, it may be suggested that the gas sand in this area is really in the form of discontinuous lenses, but in either case the conditions do not appear favorable for the development of commercial quantities of gas, though it might be worth while to prospect some of the adjoining territory.

CORSICANA.

Corsicana has been the center of both oil and gas production, but the value of oil has been much greater than that of gas. Petroleum was discovered in this region more than 15 years ago, and although the field has never been a large producer, its aggregate output has been large. It is remarkable for the great number of wells that have continued to produce for several years. One well near the city of Corsicana has yielded oil since September, 1898.

Two distinct kinds of petroleum are produced, one being a light oil suitable for refining and the other being much heavier and better suited for fuel oil. The light or high-gravity oil is found near Corsicana, and the heavier oil farther east toward Powell.

Gas has been found at various places in the oil field, but most of the wells have had a small production and have lasted only a short time. The only commercially important gas fields near the town of Corsicana are about 2¾ miles a little west of south of Powell and 1 mile south of Chatfield. These two fields have supplied gas to the city of Corsicana. The Powell field has an approximate length of 1¼ miles and a width of a quarter to half a mile. Several wells have been drilled in this field, the most productive being Stone No. 2, which was about 890 feet deep and had a pressure of 375 pounds to the square

inch. This well supplied gas to the city of Corsicana for about three years. There was so much salt water with the gas that it was necessary to install a large separator at the well, and all the wells subsequently drilled found more or less salt water associated with the gas. Additional wells were drilled in this pool to supplement the supply from the first well, and some of the earlier wells are now dead. Two or three of the wells would still supply some gas, but the pressure is so low that it could not be utilized without compressors, and it is doubtful if the amount of gas that could be obtained from the wells would warrant the expenditure of much money for installing compressors.

The gas pool near Chatfield occupies an area of about the same extent as the one near Powell, and four or five producing wells were drilled in it. The gas from this field was piped to the city of Corsicana and furnished about one-third of the total amount used before the pipe line was constructed from the Mexia-Groesbeck field. At present this field is entirely dead and the casings have been pulled from the wells.

Logs of wells near Corsicana, Powell, and Chatfield.

Corsicana Petroleum Co., waterworks well No. 30.

[Contractor, R. Walling. Drilled Apr. 30–May 1, 1903.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	......	3
Clay	14	17
Shale	223	240
Rock	1	241
Shale	40	281
Rock	2	283
Shell	17	300
Do	900	1,200
Rock and shell	23	1,223
Sand	20	1,243
Rock	1	1,244
Salt-water sand	10	1,254

No show of oil or gas.

Corsicana Petroleum Co., Kerr well No. 1.

[Drilled Nov. 25 to Dec. 14, 1901. Dry hole. Filled up 175 feet with salt water from sand at 1,191-1,199 feet.]

Joint clay	......	40
Shale	90	130
Water sand	5	135
Shale	5	140
Lime bowlder	2	142
Blue marl	98	240
Hard lime bowlder	3	243
Blue marl	737	980
Blue shells	205	1,185
Shale	6	1,191
Salt-water sand	8	1,199
Blue marl	204	1,603
White lime	6	1,609

Logs of wells near Corsicana, Powell, and Chatfield—Continued.

Corsicana Petroleum Co., L. B. Roberts well No. 3.

[Drilled by Houston Oil Co. of Texas, Jan. 6, 1905.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	1	1
Yellow clay	34	35
Hard bluish sand	48	83
Gravel and white sand	5	88
Brownish shale	293.5	381.5
Black quartz	58.8	440.3
Brownish shale	405.8	846.1
Top of first gas sand	....	846.1
Through sand into shale, good gas pressure	40.8	886.9
Shale	118.1	1,005
More gas sand and better pressure	18.7	1,023.7
Shale	8.3	1,032
Salt-water sand	13	1,045
Shale and bluish mud; abandoned at this depth	139.2	1,184.2

Corsicana Petroleum Co., Whiteselle well.

[Drilled Feb. 15–Mar. 5, 1904.]

Soil	5	5
Clay	16	21
Shale	45	66
Rock	1	67
Shale	195	262
Rock, very hard; case barrel	3	265
Shale	9	274
Rock, very hard	3	277
Shale	24	301
Rock	1	302
Shale	18	320
Rock	1	321
Shale	139	460
Gumbo	14	474
Shale	367	841
Gumbo	5	846
Shale	220	1,066
Rock, hard in places	4	1,070
Sand; no gas, some water	25	1,095
Shale	55	1,150

Slight traces of oil at 1,065 feet.

Anderson well No. 7, Chatfield.

[Drilled Nov. 11, 1908.]

Clay	....	10
Rock	2	12
Clay	33	45
Sand	60	105
Shale and gumbo	734½	839½
Gas sand	8	847½

Roberts well No. 1.

[Drilled Sept. 20, 1907.]

Clay	....	57
Rock	3	60
Sand	114	174
Shale and gumbo	686½	860½
Gas sand	16	876½

Logs of wells near Corsicana, Powell, and Chatfield—Continued.

Stone well No. 5.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and gravel	....	60
Shale	784	844
Rock	½	844½
Sand; showed both oil and gas	3½	848
Sand and shale	26	874
Hard sand and shale	32	906
Cap rock and sand	12	918
Sand rock	15	933
Cap rock	2	935
Sand	1	936

The oil and gas found near Corsicana and Chatfield are obtained from two or more sand beds in the upper portion of the Upper Cretaceous series, probably the Navarro formation. The well logs have a particular interest because the surface formation near Corsicana is of about the same geologic age as the gas sand at Mexia and Groesbeck, and the wells at Corsicana show the presence of sands in either the Navarro or the Taylor formation below the horizon of the sand that supplies gas in the Mexia-Groesbeck field. Sands have been found at still greater depth near Corsicana in the water wells of the city and in a deep well at the Magnolia Petroleum Co.'s refinery. The relation of these deep sands to the producing sands is shown in the diagram of the refinery well (Pl. VII, p. 78). The water obtained from these deep sands is relatively pure, though it contains enough salt to give it a brackish taste. These sands can not be expected to be productive in the vicinity of Corsicana, but they might supply oil or gas in the gas field south of Powell and possibly also at Chatfield.

CASH.

The accompanying diagram (fig. 12) shows the relations of three wells that have been drilled in the vicinity of Cash. Both Nos. 1 and 2 are shallow wells. No. 1 has a little showing of gas and a small volume of salt water. No. 2 contains enough gas to cause a heavy flow of salt water, and it is necessary to keep the well capped to avoid flooding the surrounding land. This well might possibly be utilized to supply a house, as the amount of gas would apparently be ample for that purpose. Both of these wells penetrate a shallow sand that is probably an approximate equivalent to the oil or gas sands of Corsicana. Well No. 3 has been drilled to a greater depth and found showings of oil and gas in the Woodbine sand. It did not encounter an appreciable amount of gas in the shallow sands that supplied the showings in wells Nos. 1 and 2.

The amount of information available concerning the area near Cash is not sufficient to warrant suggestions as to further prospecting,

but the fact that the sands are much higher than the sands that are correlated with them at Quinlan and Terrell and are reported to be higher than the sands of the same age at Greenville suggests that there may be an anticline near Cash and makes it seem advisable to continue prospecting.

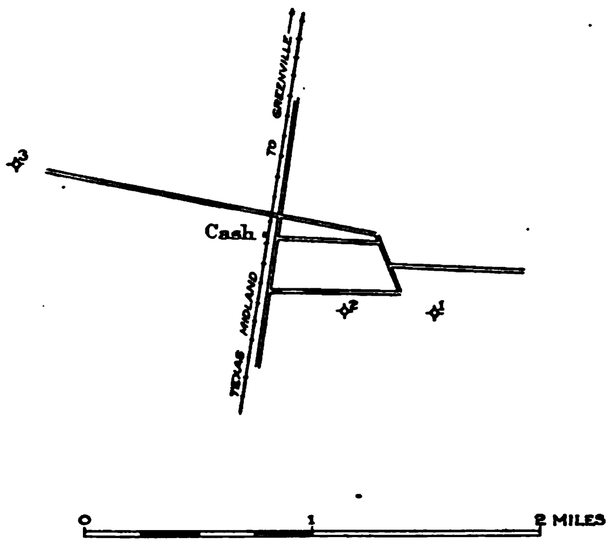

FIGURE 12.—Diagram showing the relations of wells drilled at Cash.

A few miles south of Cash in the vicinity of Quinlan some shallow wells encountered small showings of gas in a sand that is probably the equivalent of the shallow gas sand at Cash.

MABANK.

The accompanying diagram (fig. 13) shows the distribution of wells that were drilled in the vicinity of Mabank, and the figures given show the depths of the gas-bearing sand below sea level. All these wells, except the one northeast of Mabank, supplied small amounts of gas with salt water, but the structure suggested by the elevations of the gas sand is too flat to warrant the drilling of additional wells with the expectation of finding commercial quantities of gas within the area shown by the diagram.

In the region near Mabank the Midway formation is at the surface and the wells penetrate the Cretaceous rocks for a considerable distance. It is therefore inferred that the gas sand in this region belongs to the Navarro formation and that it may be tentatively correlated with the gas sand of the Mexia-Groesbeck field. Deeper sands may be struck in the Cretaceous rocks at Mabank, but they are probably of little economic importance, because the folding there is not sufficiently pronounced to permit the accumulation of much gas or oil.

SUMMARY.

Gas has been found at Baileyville, Koose, Thornton, Groesbeck, Mexia, Wortham, Currie, Richland, Corsicana, Powell, Chatfield, Mabank, Cash, and Cooper. At only three of these places have wells

furnished gas in commercial quantities and at only two have wells furnished oil; but the significance of the presence of gas in the area between Baileyville and Cooper is not affected by the commercial value of the discoveries that have been made. These discoveries show the presence of gas-bearing sands through this belt, and inves-

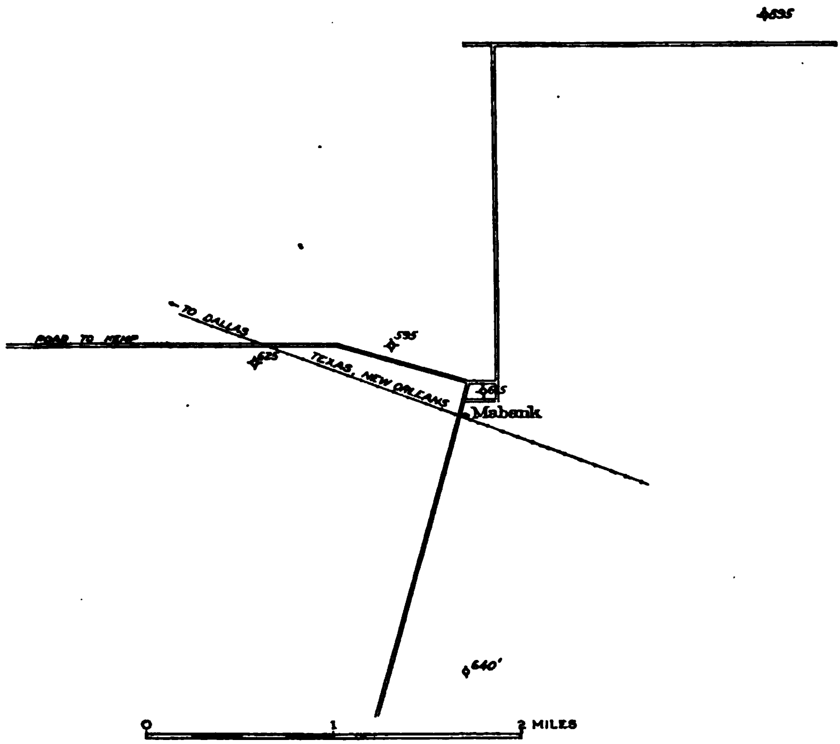

FIGURE 13.—Diagram showing the relations of wells drilled at Mabank.

tigations indicate that the dip of the beds here is not uniformly toward the southeast but is interrupted by terraces and minor reversals of dip. Sructure favorable to the accumulation of oil or gas, similar to that at Mexia, Groesbeck, Powell, and Corsicana, will no doubt ultimately be discovered in this region, which is therefore regarded as a possible oil and gas field.

NOTES ON THE GAS FIELDS OF CENTRAL AND SOUTHERN OKLAHOMA.

By Carroll H. Wegemann.

THE GENERAL SITUATION.

Scattered through Muskogee, Okmulgee, and northern McIntosh counties, along the southern edge of the great Oklahoma oil and gas fields, are numerous areas that have produced natural gas in great quantities. Fields near Henryetta, Schulter, Okmulgee, Boynton, Haskell, and Muskogee contain wells whose initial flows are reported to have ranged from a few million to 40,000,000 cubic feet a day. Over much of the area the gas is directly associated with oil pools and has been developed and, it must be admitted, wasted in connection with the production of oil. The gas is found in the oil sands and in sands overlying them and has proved more or less of a hindrance in the immediate production of oil. The far-reaching effects of the presence of the gas in increasing the amount of oil recoverable from the sands has been appreciated by few of the oil operators. The various methods of wasting the gas above ground or beneath the surface have been discussed too often to require description here, but the fact remains that vast stores of valuable gas have been dissipated, and that even now it is difficult for companies interested in the preservation of the gas to avoid the bad effects of too heavy drains on the gas reservoirs in neighboring properties over which they have no control. The Bureau of Mines and the State authorities have already taken steps to conserve the remaining gas supplies, and it is believed that their action will eventually lead to greatly improved conditions in the gas fields.

Active drilling is still in progress in the Muskogee-Okmulgee field, and new areas of productive oil and gas territory are being brought in. Undrained areas of gas probably remain in the vicinity of some of the old oil fields. It is doubtful if other gas pools as great in extent as those already developed will be found in this old area, but it seems safe to say that careful drilling throughout this area may open many large gas wells whose product could be utilized if pipe lines were available. It is evident, however, from the amount of drilling already done in the region and the quantities of gas already taken

out that the productive gas wells yet to be drilled must be scattered over a considerable area, and the expense involved in building lines to them will be proportionately great—so great, perhaps, as to reduce considerably the distance to which the product can be transported with commercial success.

The life of gas wells in this region varies greatly, being governed by the thickness and porosity of the various sands, but most of all by the methods used to prevent waste and the management of adjacent wells. A few wells that show large volumes when brought in decline quickly in production, probably because the gas sands that supply them are of small extent. The rapid decline of other wells and their "drowning" with salt water are undoubtedly the result of drawing too heavily on them or on wells adjacent to them. However, it is not unusual to find wells which under careful management have yielded gas for two or three years with but little diminution in volume.

South of the main area of the oil and gas fields above described and separated from it by broad stretches of unproductive territory are several gas fields, recently developed, in which the gas does not appear to be associated with oil in any great quantity. Two of these fields have been examined by the writer, and brief descriptions of them are given below. Additional details will be given later in a report with maps covering portions of the region discussed in these notes.

CHECOTAH GAS FIELD.

The Checotah gas field lies about 5 miles south of the town of Checotah, in McIntosh County. The first productive well was completed on February 10, 1914, and up to the time of the writer's examination (November, 1915) seven gas wells had been drilled, having initial volumes ranging from 1,500,000 to 15,000,000 cubic feet a day. The principal yield of gas is obtained at depths ranging from 1,970 to 2,100 feet, although gas in paying quantities (1,000,000 to 2,000,000 cubic feet a day) is found in most of the wells at 600 to 700 feet below the surface, and in some parts of the field a third gas sand at depths of 1,500 to 1,600 feet is reported. A list of the wells follows:

Green River No. 1, SW. ¼ SW. ¼ sec. 29, T. 11 N., R. 17 E.; completed Feb. 10, 1914.

Green River No. 2, NE. ¼ NW. ¼ sec. 32, T. 11 N., R. 17 E.; completed June 7, 1914.

Green River No. 3, SW. ¼ SE. ¼ sec. 30, T. 11 N., R. 17 E.; completed Oct. 22, 1915.

Gladys Bell No. 1, SW. ¼ SE. ¼ sec. 29, T. 11 N., R. 17 E.; completed Oct. 26, 1915.

Gladys Bell (Bunker Hill Oil Co. No. 1), SW. ¼ SE. ¼ sec. 36, T. 11 N., R. 16 E.; completed July, 1914.

Markowitz & Kell, C. D. Cook No. 1, SE. ¼ SW. ¼ sec. 25, T. 11 N., R. 16 E.

A shallow well, 645 feet in depth, in the SW. ¼ NE. ¼ sec. 32, T 11 N., R. 17 E.

Four dry holes have been put down in the vicinity of the field, in the NE. ¼ NE. ¼ sec. 35, T. 11 N., R. 17 E., and the SE. ¼ SW. ¼ sec. 4, NW. ¼ NW. ¼ sec. 16, and NW. ¼ NW. ¼ sec. 20, T. 11 N., R. 16 E.

The structural feature on which the gas is found appears to be a dome slightly longer than broad, its longer axis trending in a northeasterly direction. Wells Nos. 1 and 2 of the Green River Oil Co., in the SW. ¼ SW. ¼ sec. 29 and the NE. ¼ NW. ¼ sec. 32, T. 11 N., R. 17 E., appear to be on the crest of the dome. From these wells the gas pool probably extends for about 2 miles to the southwest and possibly farther, its limits not having yet been fully defined. If the structure is fairly regular, as it appears to be from the rather meager data at hand, the gas pool may be expected to extend for about 1½ miles northwest and southeast of Green River wells Nos. 1 and 2, or, in other words, the gas pool probably has a width of about 3 miles. Its extent toward the northeast is uncertain, but it seems reasonable to assume that the pool may extend in this direction for a mile or a mile and a half from its highest point. The area of the gas pool as a whole is probably about 10 square miles. It seems unlikely that oil will be found in large amount associated with the gas of this field, although it must be admitted that the borders of the gas territory have not yet been tested.

The rocks in the Checotah field belong to the Pennsylvanian series of the Carboniferous system, as shown by the presence of a coal bed about 3 feet thick, reported in the logs of some of the wells at about 800 feet. The strata recorded in the several well logs appear to be comparatively uniform in thickness, and exact correlations can therefore be made between the wells. The sand from which the principal supply of gas is derived is about 50 feet thick, but the gas is not distributed evenly through the sand, lying rather in pay streaks, each of which is from 5 to 20 feet in thickness.

A gas field 10 square miles in area, with wells yielding, according to reports, from 1,500,000 to 15,000,000 cubic feet of gas as initial daily production, is capable of producing, if properly drilled, an enormous quantity of gas. The life of the wells and the life of the field as a whole will of course depend on the care with which the gas supplies are protected from leakage and from invasion by water.

Some evidence noted in the field, which was not, however, amplified by a detailed examination, seems to show that the dome on which the gas wells are located lies on a general axis of uplift extending in a northeasterly direction, and it is possible that other small domes may be discovered on this axis to the northeast of the present field.

ADA GAS FIELD.

The Ada gas field is in Pontotoc County, one mile west of the town of Ada. The field has been developed within the last 15 months, and

up to the time of the writer's examination (November, 1915) 10 gas wells had been put down, all in T. 4 N., R. 6 E., as follows:

MacThwaite Oil & Gas Co.:
- Allen No. 1, SW. ¼ NE. ¼ SE. ¼ sec. 31.
- Allen No. 2, NE. ¼ NE. ¼ SE. ¼ sec. 31.
- Carney No. 1, SW. ¼ SE. ¼ NW. ¼ sec. 31.
- Harden No. 1, SE. ¼ SE. ¼ NE. ¼ sec. 31.
- Charlton No. 1, SE. ¼ SW. ¼ sec. 31.
- Erwin No. 1, NE. ¼ SE. ¼ SE. ¼ sec. 31.

Skelly & Sankey:
- Bruner No. 1, NW. ¼ SW. ¼ SE. ¼ sec. 31.
- City of Ada No. 1, NW. ¼ NE. ¼ SE. ¼ sec. 31.
- Ford Harris No. 1, NW. ¼ SW. ¼ NW. ¼ sec. 32.

Skelly Cantwell No. 1, NW. ¼ SW. ¼ SW. ¼ sec. 32.

Rex Oil & Gas Co.: Cassie Leader No. 1, SW. ¼ SE. ¼ sec. 30.

Both the surface rocks and those encountered in the wells belong to the upper part of the Carboniferous system and consist of sandstones, limestones, and shales that vary considerably in thickness and character from one well to the next, so that it is somewhat difficult to make accurate correlations from the well logs. The gas pool appears, however, to be situated on a small dome the longer axis of which trends N. 72° E. The dome appears to be somewhat irregular, and it is probable that the lower limit of the gas pool is by no means a horizontal plane. On the southwest and northwest the gas-producing area is limited by dry holes, but on the northeast prospecting is still in progress, and the extent of the pool in that direction is as yet unknown. It is probable, however, from the shape of the fold as already apparent, that the gas-producing area is not more than 1½ square miles.

The principal supply of gas is found at depths ranging from 1,000 to 1,200 feet and is derived in most of the wells from two beds of sandstone which range from 10 to 40 feet in thickness and are separated by 25 to 50 feet of shale. The initial flows of the wells range from 2,500,000 to 16,000,000 cubic feet of gas a day, and the initial rock pressure runs as high as 440 pounds. Single wells appear to be capable of producing without injury between 400,000 and 500,000 cubic feet of gas daily. One of the wells shows a little oil when the gas is drawn on heavily, but oil in notable quantity has not yet been found in this field.

POOLS IN CARTER AND STEPHENS COUNTIES.

No report on the gas fields of central and southern Oklahoma would be complete without reference to the gas pools in Carter and Stephens counties. In Carter County the largest gas wells are found

at the southeast extremity of the Healdton oil pool,[1] in sec. 15, T. 4 S., R. 3 W. The initial volume of one of these wells, drilled in February, 1915, was reported as 40,000,000 cubic feet a day. Gas sands above the principal oil sands are found in most of the oil wells on the Healdton dome, and large supplies of gas, to which little attention is paid, have already been developed in the search for oil in this field. In October, 1915, a gas well with an initial volume of 18,000,000 cubic feet a day was drilled southwest of the village of Fox, about 8 miles north of the Healdton field.

In the Loco field,[2] which lies in secs. 9, 10, and 15, T. 2 S., R. 5 W., 3 miles southwest of the town of Loco, 9 productive wells have been drilled which have tested a territory about 1½ square miles in extent. The gas wells range in initial volume from about 6,000,000 to 20,000,000 cubic feet a day. The gas has not yet been utilized, but it is understood that a pipe line to the field is contemplated.

The Duncan gas field[3] lies in sec. 12, T. 1 N., R. 6 W., about 10 miles northeast of the town of Duncan, or 15 miles north of the Loco field. Six gas wells have been drilled, all in one section, and the producing territory is probably of comparatively small extent. The wells, however, show initial volumes of 3,000,000 to 18,000,000 cubic feet a day, and the town of Duncan obtains its gas supply from them.

GAS FROM DEEPER SANDS.

In these notes no consideration has been given to the possibilities of striking deeper sands in the pools. There should, in fact, be a number of underlying sands in the Pennsylvanian series in most of the pools, though it can not be certainly predicted whether they will be found to contain gas, oil, or water. The pools farther south, such as the Checotah pool, are more likely to contain gas than oil in large amounts in the deeper sands. If gas is present in lower sands it should be under greater pressure and therefore more productive area for area. It will be noted that the drilling in these pools has generally gone but little below 2,000 feet, some of the wells being less than 1,200 feet deep. In the course of time these pools will undoubtedly be drilled until the lowest sands that can be reached by modern methods have been tapped.

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[1] Wegemann, C. H., and Heald, K. C., The Healdton oil field, Carter County, Okla.: U. S. Geol. Survey Bull. 621, pp. 13–30, 1915 (Bull. 621–B).

[2] Wegemann, C. H., The Loco gas field, Stephens and Jefferson counties, Okla.: U. S. Geol. Survey Bull. 621, pp. 31–42, 1915 (Bull. 621–C).

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CONCLUSIONS REGARDING OKLAHOMA.

In conclusion it may be stated that the gas resources of central and southern Oklahoma are sufficient, if protected from waste and properly handled, to furnish supplies to such cities as Dallas and Fort Worth for years to come. The gas is, however, for the most part distributed over large areas in many pools of comparatively small size, and it may prove unprofitable under present conditions to build pipe lines of sufficient extent to collect it. Among the larger gas pools may be mentioned the field south of Checotah, in McIntosh County, which is at present being drilled. The large supplies of gas in the immediate vicinity of the Healdton oil field are worthy of careful consideration, especially since the bringing in of the new gas well near Fox, north of the field, which suggests the possibility of the presence of other gas pools in this vicinity.

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